Keystone Sector Identification

Maureen Kilkenny and Laura Nalbarte

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About the Authors

Maureen Kilkenny is an Assistant Professor in the Department of Economics, Iowa State University. Laura Nalbarte is a graduate student in Statistics at Iowa State University.

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1. Introduction

This paper presents a new method for identifying *keystone sectors* in communities, where sectors are broadly defined to include churches, clubs, associations, and public institutions, as well as different types of businesses and industries. In an arch, the keystone is the one with the unique shape at the top of the arch that is critical for the arch's structural stability. The term *keystone species* was first coined by ecologists in the late 1960s with respect to the species" responsibility for the structure and integrity of an ecosystem. We now coin the term for use in community development analysis. In a community, the keystone sector is the one that plays a unique role and without which the community is fundamentally and detrimentally altered.

This research has been financed by the Tennessee Valley Authority (TVA) Rural Studies Program. The TVA Rural Studies Program's mission areas include finding new ways to describe and analyze rural economies, enhancing entrepreneurial/business activity, and supporting innovative community change. The tasks of the research are to develop new methods to (1) quantify rural community structure, (2) describe the roles of all types of entities, and (3) identify the critical, or keystone, entities in a community. These tasks address the TVA Rural Studies Program's three mission areas. To efficiently enhance entrepreneurial/business activity, an agency may wish to target public support to the *keystone sector*. Our new method may identify sectors (broadly defined) not identified using the prevailing "critical sector" or traditional "industrial targeting" approaches familiar to economists.

Prevailing Methods

I-O Based Methods

There is a long tradition among applied economists seeking useful answers to the question: "What should be given priority for economic development funds or special credit?" *Target industry analysis*, developed by TVA, is the prevailing method used to respond to this question. *Target industry analysis* (a.k.a. critical sector or turnkey industry analysis) attempts to match industries with locations for the mutual benefit of the firms and the communities. The method keys off the identification of relatively *dominant industries*, those sectors with relatively high location quotients, that also have a number of input-output linkages with other local industries with high location quotients. The inference is that industries that are already in the area are the best indicators of industries that should be recruited. Two approaches are typically used to estimate the size of the potential market. An *industrial linkages* approach uses (national) input-output industry $\times$ industry intermediate use coefficients $\times$ local industry activity. A *trade area* approach estimates final demand, taking distance, population density, and local income into account using a gravity formula.

Consider the popular *linkages* approach. In a record of a community's input-output transactions, the strength of the effects of a purchasing sector on the sectors it purchases from, or *backward linkages*, are given by the column coefficients for the sector in the multiplier matrix.[1] The *forward linkages*, or the effects of a sector on the other sectors it sells to, are given by the row coefficients of the multiplier matrix. What economists have been calling critical or key sectors are those sectors whose structure of backward and forward linkages create above-average impacts on the rest of the economy (Sonis et al., 1998; Cella, 1984). These would be the sectors whose column and/or row coefficients are higher than average.

> Any unit change in final demand of a particular sector will affect demand and supply of intermediate inputs. The demand stimulates other domestic sectors to satisfy its intermediate requirements (backward linkage). The supply also stimulates domestic production because it may induce use of its output as an input in new activities (forward linkage). Interdependencies among productive sectors indicate each sector's potential capacity to stimulate other sectors. Activities having the highest linkages are considered key sectors because by concentrating resources in them it should be possible to stimulate a more rapid growth of production, income

and employment than with alternative allocations of resources (Cella, 1984).

The strengths of input-output based methods are that (i) the bi-proportional sector-sector transactions table is a popular and useful way to document sector interdependencies, (ii) the definition of the system boundary is very operational (i.e., $Y = AY + X \Rightarrow Y = mX$ where $m = [I-A]^{-1}$), and, (iii) the I-O methods have proven useful in many other contexts. The weaknesses of I-O based methods include (i) I-O data are prohibitively costly to collect, thus (ii) the most recent national table is for 1987 (too old), (iii) there is no comprehensive sub-national data, and, (iv) the I-O approach is limited in scope: only business transactions are considered. There is no consideration of the roles of other entities in a community.

Revealed Comparative Advantage

Another way used to determine which industries to target for an area is to survey existing businesses in attempts to identify the *regional comparative advantage*. In general, a region's comparative advantages are those activities which employ their relatively abundant factors of production most intensively (Hechscher-Ohlin-Samuelson); or, those industries in which local producers are more productive (fewer inputs per unit output) than other region producers (Ricardian). The regions with the resources or technology to produce certain items relatively more cheaply should be able to profit most by specializing in those items. Market frictions, however, such as labor or capital immobilities, or, high fixed or transport costs, can undermine these hypothetical gains from specialization and trade in comparative advantage goods. Alternatively, some analysts assume that a region's comparative advantage sectors are revealed by their existing production and trade patterns. The deduction is that if a region is specializing in and exporting something, it must be it's comparative advantage sector.

Rather than attempting to assay local factor endowments or productivity objectively, a direct survey approach is often used. Businesses are asked about the location's proximity to input suppliers and/or output consumers, labor force costs, energy costs, and the industrial climate established by the state/local government, among other things. Their answers are used to profile a region. The validity of the approach relies on the objectivity of the survey respondents and their abilities to compare their chosen locale's feature to the features of other locations. Their answers to the questions are then interpreted in comparison with other previous studies. The conclusion drawn is that industries which have located in areas with comparable profiles may be interested in locating in the study area as well (Goode and Hastings, 1988).

The lists of industries that may desire to locate in the region (identified by either of the methods described above) are then screened for desirability for the community on criteria including wage rates or value-added per employee, demand for the unemployed portions of the local labor force, ability to serve regional excess demands, expected growth potential, and other location specificities.

Results of Targeting Critical or Comparative Advantage Sectors

The results of even the "successful" industrial targeting programs, however, have been criticized for merely crowding-out private activity or being an imbalanced use of funds (Jacobs, 1985). If no market failure has been identified, why would public support be needed by any critical or comparative advantage sector that is valued and profitable in a location? If there are no market failures, public support does only what the market would have done anyway (crowding out), and, at a higher cost. The case of an imbalanced use of funds is one of too much capital investment in one type of industry. Outward signs of "too much" investment in one type of activity include (i) environmental degradation, (ii) stagnation or decline in other sector activity, (iii) leakages of capital-related income, and (iv) migration out of the area.

An analogy is that industries induced to locate in an area by subsidies and tax holidays may ultimately behave like predators. In addition to using up tax revenues, the industries may "feed" on the output of local industries, destroy natural resources, and eclipse existing industries that compete for labor, similar inputs, or similar consumers. When only certain industries are targeted, the diversity of the local economy can be reduced, making it more sensitive to exogenous shocks originating in those sectors. Finally, especially if it is the major employer, an industry designated as "critical" can more effectively threaten to abandon the community if substrate supplies, subsidies, or other attractions diminish (Kilkenny and Wolhgemuth,1996). If such industries succeed, the predator relationship (analogy) may turn into a parasite/host relationship.

Keystone Species Concept

The *dominant industry* and the *predator* analogy discussed above are a natural point of departure. In this project, we apply the *keystone* concept developed by natural scientists to the social science analysis of economic systems. We do this by formulating a test of "keystoneness" that uses the techniques of graph theory from mathematics and social network analysis from sociology, and applying it to analyze data about a single local economy.

The concept *Keystone Species* was first coined by ecologist Robert Paine in the late 1960's, in his identification of a predator as the critical species in an ecosystem. Paine described the effect of removing a species of starfish, the main predator on mussels, from a rocky intertidal zone. Without the starfish, the whole system changed. The mussels proliferated, leading to a significant change (increase) in biodiversity. Paine called the starfish a *keystone species*:

> The species composition and physical appearance were greatly modified by the activities of a single native species high in the food web [starfish]. These individual populations are the keystone of the community's structure, and the integrity of the community and its unaltered persistence through time...are determined by their activities and abundances (Paine, 1969).

Over the decades, the *keystone species* concept has evolved beyond it's focus on predators, but it remains "poorly defined and non-specific in meaning," (Mills, Soule and Doak, 1993). Natural scientists have tended to proliferate studies arguing the "keystoneness" of their favorite organism.

In addition, the implied assumption that there will always be one and only one keystone in a system is suspect. Plants, micro-organisms, prey, the physical environment, and other aspects in an ecosystem may all play critical roles. As Princeton University ecologist Simon Levin says, "focusing on particular species often misses a great deal of what's important in an ecosystem" (Stone, 1995). By analogy, in the analysis of community economic systems, the exclusive focus on only one type of species (private sector businesses) may also "miss a great deal of what is important."

It is instructive to note that the original "top-down" keystone species concept in Biology has been fundamentally challenged by a more holistic, "bottom-up" concept of *functional groups*, which recognizes that small organisms on the bottom of a food chain can also determine an ecosystem. The *functional group* concept is exemplified by the work of Robert Stenek, who studied a "curious pattern of continuity in the face of drastic change" among algae clusters floating around the Caribbean island of St. Croix. "Almost none of the dominant species I'd find in one season would I find as dominant in the next," Stone quotes Stenek, but "what was going on in the mats varied little: They consumed nutrients at a fairly constant rate and resisted similar types of predators. Different algae, apparently, were performing the same biological role" (Stone, 1995). It is now widely understood that "whole suites" of organisms have similar functions in an ecosystem, and their role can be modeled as a single group rather than separately for each species.

The *functional group* notion in biology corresponds to the economic notion of *substitutes*: inputs in production, or outputs in supply. Ecologists are now trying to develop methods to identify influential functional groups; i.e., *keystone functional groups*. By analogy, we (economists) seek to identify *keystone sectors*, where a "sector" or group of sectors corresponds to a "functional group" whose members substitute for one another.

In what follows, we define a community to be the set of businesses and institutions in a single geographic location, such as a town or city. We define the *keystone sector* to be the type of businesses or institutions, private or public, which play a unique and critical role in achieving the objectives of a community. We use a subset of graph theory (Berge, 1962) called *network analysis* (Wasserman and Faust, 1994) to analyze the interrelationships between varied entities, identify "species," and test for the sensitivity of the system to the absence of each species.

Preliminary Analyses

As a preliminary step, we analyzed a survey of small businesses (Kilkenny, Nalbarte, and Besser, 1999) in 30 small communities in Iowa. We were looking for a way to document the interdependencies among businesses, institutions, and local citizens. We tested and found statistical support for the "social embeddedness" hypothesis: businesses whose owners or managers make more donations to their community and/or who serve as volunteers or as an elected public servant, feel twice as successful as those who do not. The service, however, must be reciprocated by community support of the business. There is no evidence of differences across sectors or across towns by size. Neither the activity of the business nor the size of the town was found to be relevant. The findings are the same regardless of community sizes or different business activities.

We further concluded from our work "Reciprocated Community Support and Small Town-Small Business Success" that the usual market interactions and economic characteristics of business activity, typically thought to be most relevant in explaining firm success, *were far less relevant than non-market interactions*. This was a surprising finding, but not an unprecedented one. Kranton (1996) has argued that non-market reciprocal exchanges are a substitute for search and/or transaction costs. Non-market transactions can also help reduce damaging opportunistic behavior among strangers.

Economists concerned with the political economy of growth have also focused recently on the relationship between social capital and macroeconomic performance (Putnam, et al., 1993; Knack and Keefer, 1997). Almost all of these studies attempt to measure a dependence of macroeconomic performance (growth in regional or national gross product) on region-wide indicators of associational activity, trust, and civic cooperation. The hypothesis is that high-trust societies waste fewer resources protecting themselves from malfeasance; have cheaper, more credible and stable governments institutions; have more access to credit; and risk more on innovation—all of which lead to higher rates of national investment and national growth (Fukuyama, 1995; Knack and Keefer, 1997).

In "Reciprocated Community Support and Small Town-Small Business Success" (Kilkenny, et al., 1999), we relied on one side's opinions of how the other side feels: only one side of an interaction was interviewed. We learned that to test hypotheses concerning reciprocity, it is necessary to sample both sides of the relations.

2. Graph Theory and Network Analysis

In this section we describe the application of some existing tools (albeit rarely applied in economics) to our basic question: What entity or entities are critical in a small community? If we can answer this question for one community, we may be motivated to develop the techniques to answer the question about a sample of communities. (Generalizations should not be drawn from observations about just one community.)

First, we propose how we plan to identify the "keystone" in a single community. We learned from experience with I-O based models and our work on "reciprocated community support," that we must identify the keystone sector(s) from among *many* possible types of entities, taking into account all the possible interdependencies in a community. We sought a methodology that could be applied to do at least three things: (1) describe interdependencies within and among agents, institutions, sectors and communities; (2) determine the degree of importance of an agent or groups of agents; and (3) determine the sensitivity of the structure of the community to the excision of particular agents. Network analysis methods are appropriate for all three tasks.

Network analysis has been widely used in transportation system research (Hanson and Huff, 1986; Koppelman and Pas, 1985; Wright, 1979) and anthropology and sociology research (e.g. Granovetter, 1973; Freeman, 1977). Applications of graph theory or network analysis to identifying critical sectors, however, are scarce. The few attempts include the early work of Campbell (1975), and some recent initiatives by Kauffman (1988), Roy (1994, 1995), and Sonis and Hewings (1997).

Statistical models based on graph theory, however, have been used by researchers to study social networks for almost 60 years. The goal of these models was (and remains) the quantitative examination of the stochastic properties of social relations between the actors of a particular network (Wasserman and Pattison, 1996). Applications range from studies of interactions between individuals: interpersonal relations, friendship, leadership, etc., to studies of interactions between groups: global studies of communities, studies of the élite and political behavior, and studies of power-sharing. A social network consists of a finite set of *actors* and the *relation* or relations defined on them. Actors are social entities, discrete individuals, corporate or collective social units (Wasserman and Faust, 1994).

> Social network analysis may be viewed as a broadening or generalization of standard data analytic techniques and applied statistics, which usually focus on observational units and their characteristics. A social network analysis must also consider data on ties among units (Wasserman and Faust, 1994).

Such data on ties are known as *relational data*. Typically, relational data are collected by observing or interviewing individual actors about possible linkages among the actors in the set. In this case, the unit of observation is an actor, from whom we obtain information about ties with other actors.

The basic feature of network analysis, as distinct from the more usual data analytic framework common in the social sciences, is the use of relational information to study or test hypotheses. Relational data can include, for example, data on values of purchases or sales between firms, contractual agreements between agents, information flows between one and another, the flow of money among actors, or trade links among countries. The collection of ties of a specific kind among entities in a group is called a relation. Robinson and Foulds (1980) provide the following mathematical definition of *relation*:

> Given two sets S and T, each member of set S may be related to a number (perhaps zero) of members of set T. The mathematical description of this situation is called a binary relation. If $x \in S$ and $y \in T$ then (x, y) is a member of this set when x *is related to* y.

Note that the mathematical definition of a relation is what sociologists call a tie. The link between a pair of actors is called tie. A tie is a property of the pair; therefore, a tie can not be thought to pertain simply to an individual actor. Social network data consist of measures of one or more ties among a set of actors.

When the interest is focused on measuring the ties among actors, since ties exist only between specific pairs of actors, the relevant unit of observation is the *dyad*. A dyad consists of a pair of actors and the possible ties between them (Wasserman and Faust, 1994). For example, two cities connected by a commuter's travel pattern between them form a dyad. The researcher could be interested in estimating the direction in which commuters are more likely to go, and the frequency of travel, etc.

There are two main distinguishing characteristics of ties or relations: they are i) *directional or non-directional*, and/or ii) *dichotomous or valued.* A directional relation has an explicit origin and destination. A non-directional relation is non-specific about the origin or destination of the flow on the link (Wasserman and Faust, 1994). By convention from graph theory, a non-directional relation is represented by an edge or a tie. It is illustrated by a line between the interacting agents that has no arrowhead. A directional relation is represented by an arc. An arc is a line between entities with an arrowhead at the destination.

For example, if country A exports manufactured goods to country B, the direction of trade is from A to B, reflecting B's imports from A. If the direction is not recorded, the trade flow could be misconstrued to be about exports of B. Graphically, the directed relation of A's international trade exports to B is shown as A -> B. The matrix form for recording this relation would have an entry in the A row and the B column (opposite to conventional SAM accounting convention).

A dichotomous relation is recorded as either the presence or absence of a tie between two entities in the set. Meanwhile, a valued relation records not only the existence of a relation but also the intensity or frequency of the relation (Wasserman and Faust, 1994). An example of a dichotomous relation is public safety agency A's provision of services enjoyed by business B. Since a public good is by definition non-rival, use or non-use is the relevant measure (rather than quantity used). An example of a valued directional relation is the dollar value of exports recorded as being shipped from country A to country B.

Digraphs

Relational data are often represented by graphs. If ties have a direction (are *arcs*) the graphs are called directed graphs or digraphs (Robinson and Foulds, 1980).

> A digraph is a finite non-empty set N, whose elements $\mathbf{N} = \{n_1, n_2 \ldots . n_g\}$ are called *nodes*, together with a set $\mathrm{A} = \{\boldsymbol{a}_1, \boldsymbol{a}_2 \ldots . \boldsymbol{a}_l\}$ of ordered pairs $a_{ij} = (n_i, n_j)$, called *arcs*, where $\boldsymbol{n}_i$ and $\boldsymbol{n}_j$ are distinct members of N .

A digraph can be presented both graphically and in matrix form. The graph shows how all agents in the system are related to all other agents in the system. If the number of agents is not too large, the graph shows which agent(s) is (are) connected to which others, and which are isolated; which are senders or receivers. Figure 1 is a digraph of 73 agents. It is a good example of the case where the number of agents is "too large."

Digraph data on interactions between social entities presented in a matrix are called a sociomatrix. By convention, the rows of the sociomatrix represent the sending actors while the columns represent the receiving actors (note: this is the opposite of Social Accounting Matrix conventions). A sociomatrix need not be square: The set of sending and receiving actors may be the same, or different.

Robinson and Foulds (1980) also define two other useful concepts, adjacency and out/in-degree. *Adjacency* is the graph theoretical expression of the fact that two agents, represented by nodes, are directly related, tied, or connected with one another. Let $n_i, n_j \in \mathrm{N}$ denote agents *i* and *j* in a set of N agents. Let a_{ij} denote the existence of a relation (arc) from agent *i* to agent *j*. Agents *i* and *j* are *adjacent* if there exists either of the two arcs, a_{ij} or a_{ji}. Given the digraph $\boldsymbol{D} = (\mathrm{N}, \mathrm{A})$, its adjacency matrix $\mathrm{A}(\boldsymbol{D})$ is defined by $\mathrm{A}(\boldsymbol{D}) = (\boldsymbol{a}_{ij})$, where $\boldsymbol{a}_{ij} = 1$ if either a_{ij} or a_{ji}, and 0 otherwise.

The number of arcs beginning at a node is called the outdegree of the node. Outdegree is measured as the row sum for the node in a dichotomous sociomatrix.

$$\text{outdegree of actor i} = \textstyle\sum_j a_{ij} \qquad (1)$$

The number of arcs ending at a node is called the indegree of the node. The column sum for the nodes in a dichotomous sociomatrix measures the *indegree*s of the nodes.

$$\text{indegree of actor j} = \textstyle\sum_i a_{ij} \qquad (2)$$

3. Network Analysis of a Community

In this section we apply network analysis to study a small community. From our preliminary work (Kilkenny, Nalbarte, and Besser, 1999) and from our review of network analysis and sociomatrices, we learned that we need dyadic data on a variety of entities in one community. We found this type of data in a collection complied by Lauman (1985). In the late 1970s, the sociologists Galaskiewicz and Marsden gathered information on the formal organizations in a small U.S. town. The community was nicknamed, and referred to since, as Towertown. Of the 73 entities they studied, less than a quarter were private businesses (Appendix I). They assayed three relations among these 73 entities: money, information, and support.

In this section we define network analysis measures and describe techniques to do five things. First, we describe community-wide patterns: Is there a specific structure among agents, or do agents interact randomly with each other? Second, we describe the patterns of interactions among the individual agents in the community and compare their various roles. Third, we determine the groups of individual agents whose patterns of interactions are sufficiently similar that they can be treated as *types* of agent. This step is analogous to classifying numerous individual organisms into less numerous species. If we cannot do this, the number of agents will remain "too large," as illustrated in Figure 1. Fourth, we assign ties to the sociomatrix data that we have aggregated according to species. Fifth, we test for the impact of the excision of each species from the community network. Are there any species that play such important roles that the community structure will be destroyed without them? This final step completes our identification of the "keystone" sector: the entity that is relatively unique and without which the community structure will be fundamentally disrupted.

Towertown Survey

Towertown is the nickname given to the midwestern community of 32,000 persons studied by Galaskiewicz and Marsden, and documented in Laumann (1985). A total of 109 organizations were identified in Towertown, and 73 were studied. The 73 included all manufacturing firms with more than 20 employees, banks, law firms, political organizations, associations, health institutions, educational institutions, service clubs, labor unions, city offices and departments, and churches. Galaskiewicz and Marsden interviewed the executive officers of the 73 organizations. Each subject was presented with a list of the other 72 organizations in the community, and was asked the following six questions:

1) To which organizations on this list would your organization be likely to pass on important information concerning community affairs?
2) To which organizations on this list does your organization rely upon for information regarding community affairs?
3) To which organizations on this list does your organization give substantial funds as payments for services rendered or goods received, loans, or donations?
4) From which organizations on this list does your organization get substantial funds as payments for services rendered or goods received, loans, or donations?
5) Which organizations on this list does your organization feel a special duty to stand behind in time of trouble, that is, to which organization would your organization give support?
6) Which organizations on this list would be likely to come to your organization's support in time of trouble?

From the responses to these questions, three dyadic relations were defined: INFORMATION (1,2), MONEY (3,4), and SUPPORT (5,6). An organization was determined to be "in relation to" another organization if the former organization answered yes to the first question in a pair, or the latter organization answered yes to the second question in the pair. Note that if either actor in the dyad reported the existence of a tie, a tie was recorded. In other words, for each relation R, a *73 x 73* adjacency matrix (X^R) was constructed with entries $x_{ij}^R = 1$ if the $\boldsymbol{i^{th}}$ actor has a relational tie with the $\boldsymbol{j^{th}}$ actor, and $x_{ij}^R = 0$ if not. (Also, $\boldsymbol{x_{ii}} = 0$).

Macro / Community-wide Structure

We used a relatively old-fashioned software package called UCINET IV, and verified calculations using an EXCEL spreadsheet program. UCINET was produced at the University of California, Irvine (UCI). The standard version runs on any XT-compatible with at least 256k of RAM (Scott, 1991).

Density

The first step is to study the density and connectivity of the whole network. The density measure describes general level of linkage among the actors in the community. This measure compares the number of actual to possible relations, to show how far from *completion* the graph (the community network) is. A complete graph is one in which all the actors have two-way ties to all other actors. In this case, all nodes are reciprocally adjacent to one another, and all elements of the sociomatrix are equal to one. The more actors that are connected to one another the more dense and the more complete the graph is.

The density of a digraph (*d*) is the actual number of non-reflexive arcs ($a = \sum_i \sum_j a_{ij}$) in proportion to the maximum possible number of non-reflexive arcs:

$$d = \frac{a}{N(N-1)} \qquad (3)$$

Note that reflexive ties are ignored ($a_{ii} = 0$ or are not counted). A reflexive tie is the one that a particular entity has with itself; its presence would be recorded by $a_{ii} = 1$.

Since all three sociomatrices about Towertown have the same symmetric number of actors (*N* = 73), the maximum possible number of non-reflexive arcs is 73x72= *5256*. The arcs present in the INFORMATION sociomatrix are *1264*, while the ones present in the MONEY and SUPPORT sociomatrices are *512* and *814* respectively. Consequently, the density measures are 24%, 9.7%, and 15.5% for INFORMATION, MONEY, and SUPPORT, respectively. INFORMATION linkages are more *dense* and thus, more *complete*. MONEY relations are the least dense and thus, the least complete in Towertown.

Connectivity

One way to group actors is to put them together with others with whom they are *connected* in some way. An actor is connected when there is at least one arc or set of arcs that relate the actor with another actor (Wasserman and Faust, 1994). While density and completion refer to one-step arcs, connectivity is also based on multiple-step arcs. Actors may be directly related (with a one-step arc between them) or indirectly related (more than one one-step apart). An actor can be a transmitter (the arc is away from the node), a receiver (the arc is toward the node), or a carrier (there are at least two arcs, one toward and one away). Consider a digraph of a relation between entities A, B, C, and D:

A ——→ B ——→ C   D

In the above, A is a transmitter, B is a carrier, and C is a receiver, while D is isolated. An actor is isolated when there is no arc that relates the actor with any actor in the network. The sociomatrix for this example digraph is:

	A	B	C	D
A	0	1	0	0
B	0	0	1	0
C	0	0	0	0
D	0	0	0	0

showing that A relates *to* B, and B relates *to* C, while C does not relate OUT (only IN), and D does not relate at all. Formally (Wasserman and Faust, 1994), a node is a proper source or transmitter if its indegree is zero and its outdegree is non-zero; that is, if the column sum is zero while the row sum is greater than zero. A node is a proper sink or receiver if its indegree is non-zero and its outdegree is zero, that is, if the column sum is greater than zero while the row sum is zero. A node is isolated if both indegree and outdegree are zero.

Agents in a network that are all *connected* to each other can be classified as a subset of the N actors as a group (or a *sub-graph*) called a *component*. A component is the largest subset a sub-graph, of connected actors in a network. In the ABCD example above, ABC form a group, or a component. All actors are linked to one another through *paths*. All the included actors (A, B, and C) can reach one another through one or more-step paths, but they do not connect with any actors outside their sub-graph. (A path is a sequence of arcs where each node and each arc are distinct; Scott, 1991).

Components also come in two forms: *strong* and *weak*, depending on the directions of the ties, arcs, or relational links between the members of the component. A strong component is one in which the arcs that make up the paths are aligned in a continuous chain without a change of direction. A weak component is made of actors that are linked by non-directional edges (Scott, 1991). Note that UCINET's algorithm for the analysis of components relies on the weak definition. The algorithm checks for the existence of relations no matter what the direction of the arcs. That is why we found it preferable to program our own analysis using EXCEL spreadsheets. We prefer that all tests are based on directional ties.

If a sociomatrix is dense, we expect to find a single *component*. If not, there may be multiple components of various sizes. None of the three Towertown sociomatrices are dense (recall, INFORMATION is the most dense, having 24% of the maximum number of ties). So, we expected to find multiple components in the Towertown network. But we did not. A glance at the matrices indicates that every entity has at least one source or sink of INFORMATION, MONEY, and SUPPORT. There are no columns or rows that have all zeros. Furthermore, none of the connected entities are exclusive. UCINET showed the existence of a single (weak) component for each of the three relations. The Towertown community appears to be one big interconnected group. There are no isolated actors, and there are no cliques.

Micro / Individual Roles

Now we know that there are no isolated actors in Towertown. But we also know that the links among all the actors are not all mutual. Next we apply the techniques to describe the roles of individual actors. Which actors are distinguished either because they receive a lot from other actors or because they give a lot to other actors? In this section we continue to build the network analysis lexicon by demonstrating the use of measures.

Local Centrality and Prestige

Prominent actors are those that are extensively involved in relationships with other actors. This involvement makes them more visible in the community. The *prominence* could be due to either receiving and/or transmitting. To determine which actors are prominent, we consider all the directed ties (*arcs*) originating from the actor (*outdegree*), plus all the received ties (*indegree*), plus all the indirect ties (*carriers* or *paths*) as well.

There are four measures of *prominence: local centrality, local prestige* (or rank or popularity), and two versions of *global centrality*: *closeness* and *betweenness. Local centrality* reflects the number of direct transmissions, and is thus measured simply by the *outdegrees* (or row sums) of each actor. *Local prestige* reflects the number of direct receipts, and is thus measured simply by the *indegrees* (or column sums) of each actor. Since these measures are based on the *degrees* of the nodes they are also known as *degree centrality and degree prestige* (Wasserman and Faust, 1994). The *global centrality* measures are based on the length and the number of *carrier* and multiple-step path roles.

Tables 1, 2, and 3 present the measures of local centrality and prestige for MONEY, INFORMATION, and SUPPORT. Note that UCINET measures are unstandardized with respect to the maximal number of ties in each sociomatrix. In our case with equal dimension sociomatrices, and because we are not comparing across networks in different size communities, standardization is irrelevant. But if the number of agents surveyed varied from relation to relation, or network to network, one would want to standardize each set of degree measures by normalizing with respect to the number of agents.

The first four rows in each of Tables 1-3 show the sample statistics for the “degree” measures for agents in Towertown. The mean of local centrality, for example, is the average outdegree among the 73 entities. With respect to MONEY ties (Table 1), on average, a Towertown entity *gives* MONEY *to 7* other entities in Towertown. The mean of local prestige is the average indegreee measure across all 73 entities. For example, with respect to INFORMATION ties (Table 2), on average, a Towertown entity *receives* INFORMATION *from 17* entities in Towertown.

The 5th to 11th rows in each table show the local centrality and prestige measures of the top six most central and prestigious individual entities in Towertown. For example, with respect to MONEY (Table 1), Towertown Newspaper is the most locally central, giving money to *33* other entities in Towertown. First Towertown Bank is the most locally prestigious, receiving money (presumably deposits or interest payments) from *49* entities in Towertown.

Table 1. MONEY	LOCAL CENTRALITY	LOCAL PRESTIGE
sample statistics:		
Mean	7.01	7.01
Std. Dev.	6.35	8.97
Minimum	0	0
Maximum	33	49
top six entities:		
(11) First TT Bank	28	49
(12) TT Saving bank	17	38
(13) Bank of TT	23	26
(39) TT Newspaper	33	17
(69) Family Services	3	36
(71) YMCA	4	24

Table 1 shows that four of the top six agents are both locally central and prestigious. These agents are three of the four banks and Towertown Newspaper. Family Services and YMCA, on the other hand, are only locally prestigious (high indegree but low outdegree, and both outdegree measures are below the mean). These measures identify some intuitively logical patterns and relative positions. Banks both give (make loans) and receive (accept deposits) money; and the local centrality and prestige measures document that. Also, Family Services and the YMCA both rely on volunteers and donations, so it is logical that they would show up as the major recipients of money. That the newspaper is a source of money for many entities, however, is harder to explain.

Table 2. INFORMATION	LOCAL CENTRALITY	LOCAL PRESTIGE
sample statistics:		
Mean	*17.29*	*17.29*
Std. Dev.	*11.21*	*11.22*
Minimum	*1*	*3*
Maximum	*63*	*62*
top six entities:		
(12) TT Savings bank	41	26
(25) City Council	32	43
(26) City Manager's office	43	44
(39) TT Newspaper	42	44
(40) WTWR Radio	63	62
(69) Family Service	45	36

In the case of the INFORMATION relation (Table 2), again the top six agents appear to be both locally central and prestigious. All six agents receive and give information to a significantly (>2 SD) higher number of agents in the community than the rest of the entities. The Radio Station appears to be the most locally central and prestigious in Towertown.

Table 3. SUPPORT	LOCAL CENTRALITY	LOCAL PRESTIGE
sample statistics:		
Mean	*11.12*	*11.12*
Std. Dev.	*9.42*	*10.53*
Minimum	*0*	*0*
Maximum	*59*	*58*
top six entities:		
(12)TT Savings bank	37	14
(20) Small Bus.Assoc.	38	10
(56) TT Comm.College	59	58
(57) State University	20	42
(69) Family Service	12	52
(72) Mental Health	16	36

Table 3 shows the results with respect to the SUPPORT relation. The Community College both receives and gives more support than all other entities. "In times of trouble," the Community College is willing to give support to *59* entities, and *58* entities are willing to give support to the Community College.

Towertown Savings Bank appears to be locally central with respect to SUPPORT, but not locally prestigious (has high outdegree, but the indegree value is close to the mean). This contrasts with its local centrality being lower than local prestige according to the MONEY relation. Note that Towertown Savings Bank has fewer outdegrees than indegrees, suggesting that it makes loans to fewer entities in the community than the number from whom it receives deposits. The bundling of many small deposits to make a few larger loans is the main business of financial intermediaries, known as "asset transformation." It is interesting to note, however, that this particular bank does not attract as much SUPPORT as it says it would give.

Note also that different actors are prominent in MONEY, INFORMATION and/or SUPPORT flows. Towertown Savings and Loan and Towertown Family Service entities are, however, central and/or prestigious in all three of the relations.

In sum, we have shown how to classify entities with large outdegrees as important sources of INFORMATION, MONEY, OR SUPPORT. Actors with low indegrees or outdegrees are apparently less active, less important, or peripheral to a network. Note, however, the limitations of dichotomous rather than value data. In dichotomous (0/1) data, what counts is the number of ties, not their level. While this may be quite appropriate for the analysis of non-rival types of interactions such as information and support ties, it does not fully describe rival transactions such as money ties. It is likely that agents with a few high-value MONEY ties play more important roles than can be perceived with dichotomous data. For example, a business that buys large amounts of goods and services from just a few other local businesses (who then buy from other local businesses, employ many residents, and provide many donations, and so on) may not have so many ties, but because of their magnitude, its few ties may be critical to the community.

Global Centrality

When an actor has a position of strategic significance in the overall network, that actor is considered *globally central*. Globally central actors are detected using both *closeness* and *betweenness* measures. Globally central actors are those with the shortest paths relating to all the other actors. The ubiquity of an actor's ties makes them global, and the shortness of the paths is measured by *closeness*. But closeness is not the only factor that makes an actor globally central. The *betweenness* of an actor is also relevant. Interactions between two non-adjacent actors depend, by definition, on an intermediary. The intermediaries are *between* the actors, and they can exert some control over the relations. Thus, globally central actors can have widespread effects on a community because they are more closely tied with more of the other agents, and act as intermediary for more agents than any others.

Freeman's measure of global centrality relies on the two measures of closeness and betweenness. Both measures rely on a measure of distance called a *geodesic*. Wasserman and Faust (1994) define these measures as follows:

The distance from $\boldsymbol{n_i}$ to $\boldsymbol{n_j}$ is the length of the *geodesic* from $\boldsymbol{n_i}$ to $\boldsymbol{n_j}$.

The geodesic in a graph is the length of the shortest path between two nodes.

Closeness ($\boldsymbol{C_c(n_i)}$) measures are the inverse of distance measures. As a node grows farther apart in distance from other nodes, its centrality decreases.

$$C_c(n_i) = \left[\sum^{g} d(n_i, n_j)\right]^{-1}$$ where $\boldsymbol{d(n_i, n_j)}$ is the distance (number of steps or ties in the shortest path) between agents $\boldsymbol{n_i}$ and $\boldsymbol{n_j}$ and g is network size.

Betweenness ($\boldsymbol{C_b(n_i)}$) measures the probability that a communication or path from actor *j* to actor *k* takes a particular route through agent *i*. Assume each one-step tie has equal weight, and assume that interactions will occur through the shortest routes. Then,

$$C_b = \sum_{j}^{g} \frac{g_{jk}(n_i)}{g_{jk}}$$ where $1/\boldsymbol{g_{jk}}$ is the probability that a particular geodesic (path) is chosen, $\boldsymbol{g_{jk}}$ is the number of geodesics linking

actors n_j and n_k, and $g_{jk}(n_i)$ is the number of geodesics that go through n_i.

Again, all these measures depend on the size of the network. Thus the measures must be standardized before comparisons are made between networks of different numbers of entities. In degree centrality and closeness measures, the measures are standardized dividing by $N-1$. For betweeness measures, the standardization factor is $(N-1)(N-2)$, where N is the number of agents.

The summary statistics for global centrality according to both measures, with respect to MONEY, INFORMATION, and SUPPORT relations are shown in Table 4.

The higher the closeness, the more often entities are directly tied. Note that on average there are more direct INFORMATION ties (the mean of closeness is highest) than SUPPORT or MONEY ties. The mean of *betweenness* is the average number of times an actor is articulating (is the intermediary in the shortest path), a relationship between two other actors. With respect to MONEY flows, on average a Towertown entity serves as intermediary in *89* relations between other entities.

Table 4. Global centrality (sample statistics)	CLOSENESS			BETWEENESS		
	MONEY	INFO	SUPPORT	MONEY	INFO	SUPPORT
Mean	52.34	59.06	53.42	88.51	57.68	78.73
SD	6.74	7.13	8.38	244.87	131.43	238.37
Minimum	37.50	46.75	32.00	0	0.06	0
Maximum	78.26	88.89	82.76	1762.24	1013.23	1998.32

Table 5. Global centrality	CLOSENESS			BETWEENNESS		
	MONEY	INFO	SUPPORT	MONEY	INFO	SUPPORT
First TT Bank (11)	78.26			1762.24		
TT Savings (12)	71.29			686.38		
Bank of TT (13)	64.86			409.50		
Ch. Commerce					221.83	
City Council (25)		72.73				
City Mng's office		75.79			307.84	
TT News (39)	70.59	75.00		899.85	343.87	
RADIO (40)	66.67	88.89			1013.23	
CmntyCollege(56)			82.76		253.35	1998.32
State Univ. (57)			69.90			222.42
Family Serv (69)		75.79	76.60			190.60

Table 5 shows the measures for the most globally central entities with respect to closeness and betweenness. The higher the value of closeness, the more directly an entity is linked to other entities in the community. For example, First Towertown Bank reaches the most other agents with the fewest MONEY steps. First Towertown Bank is significantly closer (more than 2 SDs higher than the mean) than other entities in Towertown. Comparing two of the banks, First Towertown Bank (closeness value = 78.26) is closer to the rest of the agents in Towertown than the Bank of Towertown (closeness value = 64.86).

The higher the values of betweenness, the more potential an actor has to control third-party relationships. Again, First Towertown Bank shows the highest betweenness measure, it appears to be in the strongest control position. In both MONEY and SUPPORT flows, the entities that appear to be the most "close" also appear to be the most "between" actors. This analysis of the MONEY relation shows that banks and the newspaper are the "main roads" to other entities. They are closely linked to, and act as intermediaries for, more other agents.

If we consider the flow of SUPPORT, the Community College has a lot of connections with the rest of the community. The global centrality of the Community College is shown both by its closeness to the rest of the agents and because it has a potentially major articulation role as evidenced by its (maximum) betweeness score.

The findings for flow of the INFORMATION relation are consistent with intuition or priors. Our analysis of the INFORMATION network in Towertown shows that the media organizations (the newspaper and radio) and the community's coordinating office (the city manager's office) are globally central.

Peripheral Entities

This digression concerns how to identify (and exclude from further consideration) the entities that are the least likely to be keystones. The actors with low values of local and global centrality are the actors that are peripheral to the network. According to the Towertown data, the entities that do not have many interactions with other entities include the unions, the churches, and some of the government offices (measures not shown). Their counts of interactions are significantly (more than 2 SD) below the means.

Two actors are notoriously peripheral in all the relations: the bankers' association and the county bar association. We ask ourselves why that might be the case? The network analysis shows that BANKS relate to many entities. Banker-members of the banking association clearly have many ties as professionals. But as an association, the association's relations with other entities are few. This may be because there is no need for the association to replicate the plentiful ties the member-bankers already have.

Entities Critical to Network Structure

Now that we know about the centrality and prestige of agents, we have filled in some gaps left from our analysis of components. In the analysis of components we showed that all Towertown entities are interconnected and there are no cliques or subgroups. But the findings of a single component in Towertown did not provide any hints that any particular agent or set of agents had unique patterns of relations. Then, analyses of centrality and prestige showed that there are differences among entities. Some, notably banks, are better connected than others. But we still do not know whether their connections are critical to maintaining the structure of the community. This section presents tests for this aspect of "keystoneness." If the single-component structure of the Towertown network is destroyed by the excision of an entity, that entity is considered critical for the maintenance of Towertown's structure.

Cut-points

Entities that are vital for the connectivity of a network are those without which other entities will become isolated. Now we shall test if any individual actors that have been shown to be central are also critical to maintenance of the network structure. The central entities are, one at a time, removed from the data (their rows and columns deleted from the three sociomatrices). Then we conduct another analysis of components. If the new network has more subgroups or components, the excised entity is a "*cut point*." More formally, a cut-point is the actor whose removal from the system would increase the number of components by dividing the graph into two or more separate subsets (components) between which there are no connections (Scott, 1991).

The results are that some of the entities we identified above as central are also cut-points. In the MONEY relation, isolated actors were produced by removing three entities: First Towertown bank, Towertown Savings Bank, and/or Family Services. Removing any one of the two banks and/or Family Services breaks the single Towertown network into five components: two isolated actors: 1) the County Medical Society, and 2) the Association of Churches; two isolated dyads comprised of 3) the Municipal Employees Union I and the Central Labor Union; 4) University Methodist Church plus the Association of Churches in another dyadic component, and 5) all 64 others in the remaining component.

Similar results were found with respect to the SUPPORT relation. Removing central actors Towertown Savings and Loan, Towertown Community College, and/or State University breaks the single component structure into three components. The three components are: 1) The four Unions in one component, 2) The democratic Committee and the County Housing Authority in another component, and 3) all the 64 others in the remaining component.

With respect to INFORMATION, however, no entity appears to be critical. There is no change to the structure due to the removal of any actor. The single component structure in INFORMATION relation is robust. There is no single agent that does not have a substitute as a vector of information in Towertown.

Block Modeling

To this point we have treated each entity as unique. There are at least two reasons to group similar entities. One, as the number of entities in a community increases, the patterns of interaction are more complex and detailed. The main patterns (forest) can become obscured by the details (trees). Two, it is also useful to know which entities play similar roles. "Similar role" means that patterns of interaction with all other entities are similar or, that the entities can substitute for each other. In this section we show ways to group or block entities into "sectors" in a network. Then we study the network structure with respect to sectors rather than individual actors. This last step is called block modeling.

Block modeling is another form of network structural analysis (Holland and Leinhardt, 1979). It was introduced by White, Boorman, and Breiger (1976) for the descriptive algebraic analysis of social roles. A *blockmodel* is created from an elemental sociomatrix database by doing two things. First, the entities are partitioned into discrete subsets. This step is called "blocking." Second, 0/1 ties are assigned between each pair of subsets. The following sections explain how this might be done with sociomatrix data on communities.

Blocking

The blocking procedure consists of the partitioning of the population of entities into a set of "equivalent" subgroups or blocks. The network analysis software UCINET has a procedure called CONCOR (CONvergence of iterated CORrelations). This procedure delineates blocks of stochastically *structurally equivalent* entities. CONCOR is used to identify sets of entities with distinct behavioral patterns. By analogy, we want to group the 73 individual entities in Towertown into a smaller number of "species."

Two entities are strictly structurally equivalent if they have identical ties to and from all other entities. Formally, elements $\boldsymbol{i}$ and $\boldsymbol{j}$ are structurally equivalent if, for all other actors $\boldsymbol{k} = 1,2....\boldsymbol{g}\ (k \neq i, j)$, and all the relations $\boldsymbol{r} = 1,2,.....\boldsymbol{R}$, actor $\boldsymbol{i}$ has a tie to $\boldsymbol{k}$ if and only if $\boldsymbol{j}$ also has a tie to $\boldsymbol{k}$, and $\boldsymbol{i}$ has a tie from $\boldsymbol{k}$, if and only if $\boldsymbol{j}$ also has a tie from $\boldsymbol{k}$ (Wasserman and Faust, 1994). For example, if actor 1 relates only with 3 and 4, and actor 2 relates only with 3 and 4, then actor 1 and 2 are structurally equivalent. When there is strict structural equivalence between two of n entities in a network, the sociomatrix will be of rank n-1; one of the rows (columns) contains exactly the same information as another row (column). One of those two can be deleted, or the two can be collapsed into one, without altering the connectivity of the network.

The first step in the CONCOR procedure is to calculate the correlations between all pairs of cases (ties between dyads) in the sociomatrices. The result of this first step is a square case-by-case correlation matrix. The second step is a clustering procedure to group the cases into (stochastically) structural equivalent sets (Scott, 1991). CONCOR splits the whole set of cases into subsets that all have positive correlation within each subset, and negative correlation between. Using this assignment to groups, the rows (and columns) of the original sociomatrix are permuted (their order is switched) to put the members of the subsets next to each other. The resulting matrix has structural equivalent individuals blocked together.

The structural equivalence criterion is widely used by sociologists to block individuals into groups. We learned from this experience with Towertown data, however, that for economic analysis, one must take particular care interpreting the nature of the composition of the groups that result from its application. The problem is that structural equivalence may group entities that are complements together, while entities that are substitutes may be separated. We propose the following more formal definition of substitutability in a network:

> *From the perspective of entity K, entities I and J are perfect substitutes if a slight decrease in the desirability of interacting with I leads to interacting with J instead.*

(e.g. brown or white eggs: consumers buy whichever is cheapest). In this case, we would observe either a tie between K and I, or a tie between K and J, but not both. The dyadic relations of perfect substitutes are mutually exclusive. The CONCOR procedure would treat I and J as structurally non-equivalent and put them in separate groups. Alternatively, entities I and J are complements to K when K's interaction with I is always accompanied by K's interaction with J. An example is hot tea and cups: consumers can only drink tea when they use some kind of cup.

We applied CONCOR to each relational sociomatrix separately, and for all three relations together. The CONCOR blockmodeling procedure applied to single relation Towertown data was not satisfactory. It did appear to group complementary but separate substitute entities. Groups were comprised of heterogeneous entities: mixes of businesses, voluntary organizations, and government offices. Few groups displayed a clear role division of species. Also, there was a different block structure for each relation.

But the CONCOR group structure based on all three relations simultaneously, shown in Appendix II, is quite reasonable. Compare the dozen types of entities as listed in Appendix I with the fifteen groups determined by CONCOR listed in Appendix II. Most of the groups in the second list are comprised of what we would consider to be similar types of entities (exceptions are bolded). The only agents that do *not* group in expected ways are the three law firms and the Savings and Loan. These entities appear grouped with otherwise dissimilar entities.

All seven private sector businesses, except banks, (entities 2-8) are in Block 9. Almost all of the health services, boards, centers, and associations are grouped together in Block 2. There are five groups (blocks) that are private voluntary associations, clubs, or churches (Blocks 1,4,5,6,10). All three learning institutions are grouped together in Block 3, with TT Savings and Loan (not intuitive). All three banks are grouped together (Block 11). Note that the distinct behavior of Towertown Savings and Loan, identified when centrality and prestige were studied, also sets the S&L apart from the commercial banks. Government offices are in two types of groups: public service providers are in Block 8, and the largely administrative offices are grouped with the major information providers in Block 7. The two political party committees are grouped together in Block 13; and there are two groups of unions, Blocks 14 and 15.

Since some of the blocks formed by CONCOR are clearly comprised of "substitute" entities (the two blocks of unions, the five blocks of private voluntary associations), we decided that further aggregation of the fifteen blocks would be appropriate. The minimum number of groups is three: private businesses, voluntary organizations, and public sector institutions. From all previous analyses, the banking agents displayed significantly more critical network behavior compared to all other private businesses, so we decided to distinguish banks from other businesses. Finally, we decided on four groups: 1) banks, 2) other business, 3) government, and 4) voluntary organizations (Appendix III).

We proceed to develop the methodology with this very small number of groups for ease of demonstration. Ideally, given the CONCOR results above and our preference to collapse groups of substitutes into single blocks, we would analyze a nine block structure. Those blocks would be: (1) businesses, (2) banks, (3) health care, (4) schools, (5) associations (including churches and clubs), (6) public service providers, (7) media and public administration, (8)politicals, and (9) the unions.

We also expanded the set of sociomatrices from three to four by calculating a sociomatrix we called "SERVICE," which is the transpose of the MONEY relation. The transpose shows the relation "gives something to" from the row actor to the column actor. The assumption is that all flows of money are reciprocated by something: the provision of a service, delivery of a good, or even a "good feeling" from a charitable act. This is the same convention that records foreign aid given out as an *import* of the donor country in the current account of the donor's Balance of Payments statistics. The SERVICE relation sociomatrix is qualitatively different from the MONEY relation because arc patterns are not symmetric.

Tie Assignment

After assigning individuals to blocks, ties must be assigned between blocks. We consider three common approaches to defining ties between subsets (blocks). These are: 1) *Zeroblock*, 2) *Oneblock*, and 3) α*-density* (Wasserman and Faust, 1994). The first assigns a tie if even a single pair of entities between the two blocks have a tie, the second assigns a tie only if all pairs across the two blocks have ties, and the third is a convex combination of the first two. We then propose and use a fourth approach, based on our own criteria, developed to reflect substitutability between sinks (or sources).

First, some notation: individual agents in Towertown are indexed by subscripts $i, j = 1, \ldots\ldots, 73$; while groups in the blockmodel are indexed using subscripted A, B = (banks, BIZ, Vol, and Gov). Let T be any one of the four elemental Towertown sociomatrices of dimension 73 squared, T = {MONEY, INFORMATION, SUPPORT, AND SERVICE}, and let B be the corresponding set of four blockmodel (4 by 4) adjacency matrices. The blockmodel adjacency matrices are also called *image matrices* (Wasserman and Faust, 1994). Arcs (and ties) in T are denoted t_{ij}, while arcs (and ties) between blocks in B are denoted b_{AB}.

Zeroblock Criterion: the arc (b_{AB}) between two blocks (A, B) for a given relation is 0 only if there are no arcs ($t_{ij} = 0$) from any actor (i) in the row block to any actor (j) in the column block; otherwise the block arc is 1:

$b_{AB} = 0$ if $t$ij = 0 for all i ∈ A and all j ∈ B; else $b_{AB} = 1$.

Oneblock Criterion: the arc (b_{AB}) between two blocks (A, B) for a given relation is 1 only if all possible arcs ($t$ij) from all actors in the row block to actors in the column block exist, otherwise the block arc is 0:

$b_{AB} = 1$ if $t$ij =1 for all i ∈ A and all j ∈ B; else $b_{AB} = 0$.

α-density Criterion: the arc (b_{AB}) between two blocks (A, B) for a given relation is 1 if the observed density of arcs between the two blocks (d_{AB}) is at least as large as α, and zero otherwise.

The analyst can choose any value of α; a reasonable reference value is the density of the original sociomatrix. Recall that density (d) is the actual number of non-reflexive arcs (t_{ij}) in proportion to the maximum possible number of non-reflexive arcs:

$$d = \frac{\sum \sum \tau_{ij}}{N(N-1)}$$

Applied to calculate the density of ties between blocks:

$$d_{AB} = \frac{\sum \sum \tau_{i \in A, j \in B}}{N_A N_B}$$

Setting $\alpha = d$: $b_{AB} = 1$ if $d_{AB} \geq d$; else $b_{AB} = 0$.

Sinks Substitute Criterion: the arc (b_{AB}) between two blocks (A,B) for a given relation is 1 if there is an arc ($t$ij) from every actor in the row block to at least one actor in the column block, otherwise the block tie is 0:

$b_{AB} =1$ if for all $i \in A \ \exists \ j \in B$ s.t. $t_{ij} =1$; else $b_{AB} = 0$

Sources Substitute Criterion: the arc (b_{AB}) between two blocks (A,B) for a given relation is 1 if there is an arc ($t$ij) to every actor in the column block from at least one actor in the column block, otherwise the block tie is 0:

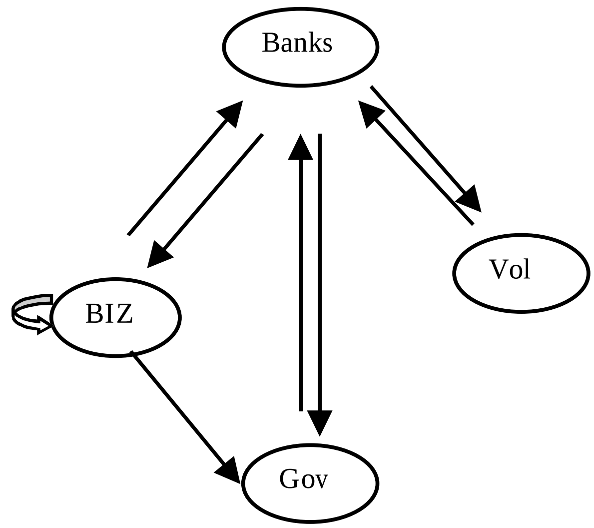
$b_{AB} =1$ if for all $j \in B \ \exists \ i \in A$ s.t. $t_{ij} =1$; else $b_{AB} = 0$

Which procedure to use should relate to one's specific objective. Our objective is to represent the relations between types of entities in communities. We have grouped Towertown entities that can substitute for one another, and we know they are not perfect substitutes. The *zeroblock* procedure is appropriate only for the perfect substitute case. If all entities within blocks are perfect substitutes, a tie by any individual in the block could be made by any other individual in the block, so even a single tie would be recorded as a block tie. But our entities are not perfect substitutes. Nor are they perfect complements. The *oneblock* procedure may be appropriate when *all* agents within each block are complements for one another. Since each entity is tied in tandem, the whole block should be tied in tandem, or not at all. The first two procedures also lead to image matrices that are either all 1s or all 0s. The *α-density* criterion is somewhere between those unlikely extremes, as are the *sink/source substitute* criteria. In sum, we developed the *substitute* criteria for the express use in analyzing blocks of substitutable entities.

In any case, we tried all the criteria to assign ties between our four blocks for the MONEY relation, and we liked our new criteria best. According to the *zeroblock* criterion, all blocks are reciprocally related (the image matrix, as predicted above, is all 1s). According to the *oneblock* criterion, none of the blocks are related (matrix of 0s). According to the *α-density* criterion, the following blockmodel and reduced graph is obtained.

MONEY (α -*density*)

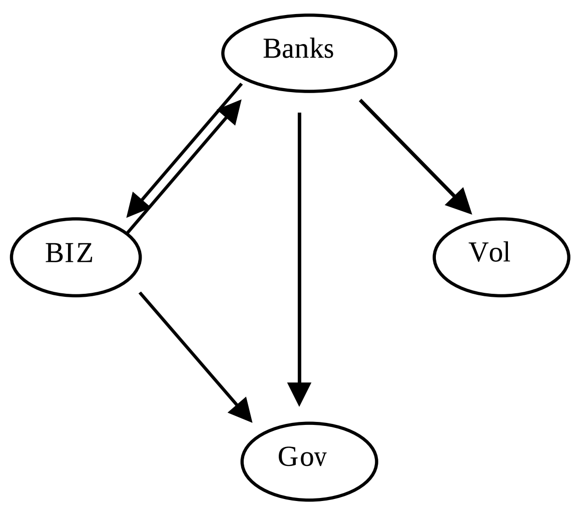
	Banks	BIZ	Vol	Gov
Banks	0	1	1	1
BIZ	1	1	1	1
Vol	1	0	0	0
Gov	1	0	0	0



In contrast, applying the *sinks substitute* criterion resulted in the following blockmodel and reduced graph.

MONEY (*Sinks Subst* Criterion)

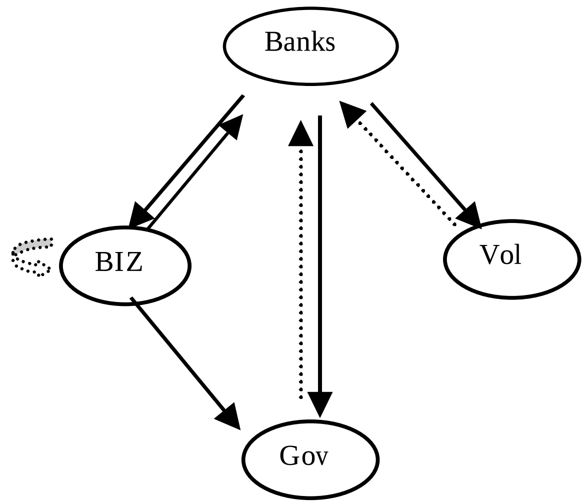
	Banks	BIZ	Vol	Gov
Banks	0	1	1	1
BIZ	1	0	0	1
Vol	0	0	0	0
Gov	0	0	0	0



Both of the *reduced graphs* of the MONEY relation show that banks and business have reciprocated money transactions as lenders, borrowers, depositors, and creditors. Furthermore, businesses and banks give money to government agencies, i.e. pay taxes. Banks give money to voluntary organizations, i.e. donations and/or loans. Note that not enough businesses supply funds directly to voluntary associations to warrant the recording of a block tie. Businesses, however, are linked indirectly to voluntary associations through banks. Banks are articulating agents.

Compare α-density to sinks/subst:

Arcs in both reduced graphs are solid. Arcs present only according to the α-density criterion are shown dotted. There are more ties between blocks according to the α-density criterion.

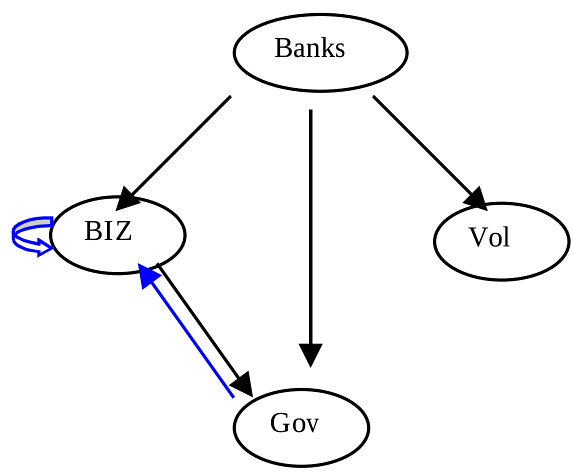


We prefer the *sinks substitute* criterion because it makes it clear that not all businesses have money transactions with other local businesses in the Towertown data, and that neither all government entities nor all voluntary associations give money to local banks. We think the tie assignment using the α-*density* criterion is too generous when the groupings are supposed to reflect substitutability.

Applying the sinks-substitute criterion to the other three relations resulted in the following blockmodels and reduced graphs.

SERVICE (*sinks subst*)

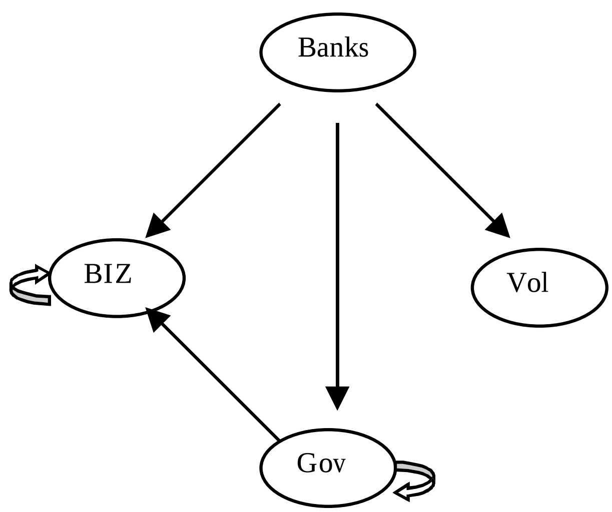
	Banks	BIZ	Vol	Gov
Banks	0	1	1	1
BIZ	0	1	0	1
Vol	0	0	0	0
Gov	0	1	0	0



The reduced digraph of SERVICE, the transpose of the MONEY relation, clearly shows that SERVICE is not simply a reverse or mirror image of the MONEY relation. In contrast with MONEY, we observe no SERVICE reciprocity between business and banks. This digraph makes it clear that local banks provide services (manage savings, provide credit) to local businesses. The MONEY relation showed that businesses pay for those services, and that if local banks buy from businesses, not all are local businesses. This digraph also shows a reciprocal relationship between local businesses and government agencies. The assumptions behind this transpose are that businesses provide services paid for by the public sector which provide services back to businesses. Interindustry transactions are also documented in this image matrix; there is a reflexive tie (arrow from/to businesses) showing that (according to our sinks substitute criterion) all local businesses in Towertown serve at least one other business in Towertown. Note that banks are (again) a critical proper source or transmitter in the system.

INFORMATION (*sinks subst*)

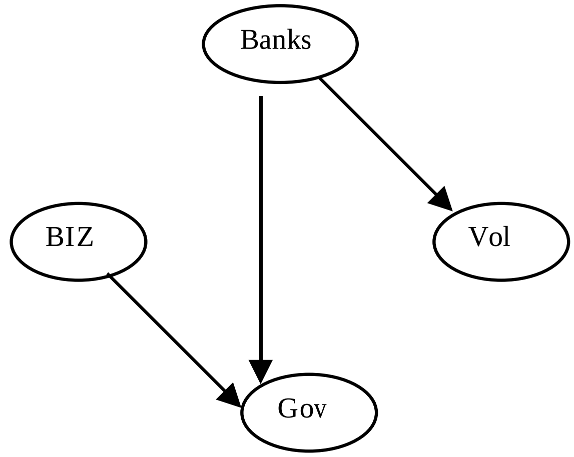
	Banks	BIZ	Vol	Gov
Banks	0	1	1	1
BIZ	0	1	0	0
Vol	0	0	0	0
Gov	0	1	0	1



The reduced graph for INFORMATION shows that information flows parallel money or service flows. Banks are again the key suppliers of information. All local businesses supply information to at least some other local businesses. And all government agencies provide information to at least some local businesses, as well as to at least one other public agency.

SUPPORT (*sinks subst*)

	Banks	BIZ	Vol	Gov
Banks	0	0	1	1
BIZ	0	0	0	1
Vol	0	0	0	0
Gov	0	0	0	0



Finally, the reduced graph of the SUPPORT relation shows that all banks "would come to the aid" of at least one of the government entities and at least one of the local voluntary associations in Towertown. It is not true that all the banks would support at least one local business. Also, all the local businesses would support at least one of the government agencies; but not all local businesses support at least one of the voluntary associations (or banks). Again, banks are significant as sources in the Towertown community.

The Keystone Test

In the introduction we posed the following definition: In a community, the keystone sector is one that plays a unique role and without which the community is fundamentally and detrimentally altered. To this point, we have identified the roles of individual entities, assigned individuals that play similar roles to groups (sectors), and identified the roles of sectors. From the image matrices and the reduced graphs, it is clear that all of the sectors play unique roles. Now it is time for the test of sufficiency: Which sectors are critical to the network? We present two tests.

Fracture Test

The first test is non-directional: If the excision of a sector fractures the connectivity of the network (breaks up the component structure), that sector is a *keystone*. There can be more than one keystone sector according to this criterion. The results of this application of the test for cut-points in the image matrix or the reduced graph, which we call the "fracture test," are summarized in Table 6.

When all sectors are present, the Towertown network is complete: the four sectors are an intact single component. The polar opposite case would be four components, each sector being a singleton. A completely dissociated community would display the maximum number of components, that is N. If businesses are excised, Towertown remains associated into one component, across all relations. This scenario corresponds, for example, to a retirement community. There is also no fracture of the remaining network if voluntary associations are excised. For example, a town of individualistic or self-sufficient atheists could nonetheless be interdependent, due to the intermediation of banks with respect to money, information, *and* support. If there are no government entities, not all businesses would remain tied in the SUPPORT network; but banks' ties with voluntary associations will remain intact.

If there were no local banks, however, across ALL relations, the single Towertown network would be fractured into two. With respect to money, service, information, and support: without local banks, the voluntary associations would be cut off, breaking Towertown into two components. One component would be the business-government dyad, the other would be the voluntary organization sector singleton.

Table 6. Fracture Test	relation			
	MONEY	SERVICE	INFO	SUPPORT
excised	number of components			
none	1	1	1	1
BIZ	1	1	1	1
Vol	1	1	1	1
Gov	1	1	1	2
BANKS	2	2	2	2

With respect to the first three of the four relations, the network is comprised of two sub-components, with banks being the common element in both sub-components. This documents that banks provide connectivity to the community. The removal of banks leads to two disconnected components. In the case of the SUPPORT relation, initially there are three sub-components. Both banks and the government sector play articulating roles.

Efficient Path Test

The fracture test is easy to apply graphically, but it is based on ties rather than directional relations (arcs). We think the source-sink directional information is relevant, so we propose an analytical alternative to the simple fracture test, which we call the “efficient path” test.

Recall that a *path* is the set of arcs between any two nodes in a relational network. If establishing and maintaining a dyadic relation is at all costly, the fewer the arcs used for a given number of components, the more efficient the network. For example, N entities could connect with each other unilaterally, requiring N(N-1) arcs (or one-step paths). If any one entity is excised, the network remains fully connected. But it is an inefficient network. Alternatively, each of the N entities could all belong to an N+1st entity, such as an association based on shared values and principles. In that case, the single component (of N+1 entities) would require only N arcs (or N one-step paths). Again, the network remains fully connected despite the excision of any one (or even any number of) the original N entities. But if the N+1st association is excised, the network would fracture into N singletons, which clearly indicates the key role the association plays in the efficient network.

In the example we give above, the N+1 association is by far the most central actor, and it is also the only articulating actor. Thus, we showed that articulating sectors not only provide coherence, they also enhance efficiency. We designed the “efficient path” test to highlight a sector's contribution to efficiency. It documents any reduction of efficiency following the excision of a sector. First, document the shortest paths (also called *geodesics*) between sectors in the original network. Then, excise a sector and recompute the lengths of the shortest paths between the remaining sectors. If the excision increases any of the other shortest paths, the excised sector has an efficiency-enhancing role, and is a candidate for *keystone* sector. Again, there may be more than one keystone sector according to these criteria.

Finding the shortest path between any two sectors requires simple matrix multiplication. Obviously, the image matrix shows all the dyads connected by one-step paths. There may also be multi-step paths between dyads for which the image matrix element is 0 (i.e., for which $b_{AB} = 0$). To find the multi-step paths, simply square, cube, and so on, the image matrix. The squared matrix will show all the dyads connected by two-step paths, as well as how many two-step paths there are between each dyad; all other possible connections will be 0. The cubed matrix shows only the numbers of three-step path dyads, and so on. Continue raising the image matrix to higher powers until a zero matrix is obtained or the pattern stabilizes. At that point, you will have gone one step farther than the longest geodesic in the network. The geodesic for each dyad is the power to which the matrix must be raised to get the first non-zero arc. Formally,

> for any digraph D with adjacency matrix $A(D)$, each entry a_{ij}^{p} of $A(D)^{p}$ equals the number of paths of length *p* from node $\boldsymbol{i}$ to $\boldsymbol{j}$ in D, for any positive integer *p* (Robinson and Foulds, 1980).

The procedure was applied directly to the digraphs (without symmetrizing them into adjacency matrices) for each of the four relations. The results are the same as shown by the “fraction test.” In all four relations, the removal of banks destroys any path to voluntary associations. Also, with respect to SUPPORT, the excision of government leaves businesses isolated.

4. Summary

This paper has presented a new method for identifying *keystone sectors* in communities, where sectors are broadly defined to include churches, clubs, associations, and public institutions, as well as different types of businesses and industries. In an arch, the keystone is the one with the unique shape at the top of the arch that is critical for the arch’s structural stability. The term *keystone species* was first coined by ecologists in the late 1960s with respect to the species’ responsibility for the structure and integrity of an ecosystem. In this paper, we developed a new method for identifying a keystone entity in any kind of system, but explicitly for community development analysis. We propose that a keystone sector in a community plays a unique role, without which the community is fundamentally and detrimentally altered.

A Replicable Keystone Sector ID Method

This paper has described and applied new ways to (1) quantify the structure, (2) describe the variety of roles, and (3) identify the keystone sectors in a community. We adapted existing methods of graph theory and social network analysis to the analysis of a local economic system. We do not know of any precedents for community level economic analysis.

The Keystone Sector ID methods we have described can be replicated easily. First, we recommend reading the book by Wasserman and Faust (1994) for a general foundation in social network analysis. Next, given a community to study, and the relations to be investigated (money, information...), assay/list all the entities in the community and decide which ones to interview as subjects. Randomly sample, or include all entities larger than a threshold minimum size as the Towertown surveyers did. Present each subject with a list of the other subjects. Ask them to indicate the others *to whom* the subject is a source, for each relation. Then, ask *from whom* the subject is a sink. Subjects could even be asked to record their ties directly in matrices.

For each relation, summarize the subjects’ responses into one matrix each. The dichotomous sociomatrices should indicate all the ties reported by all the subjects. Note that in the Towertown data, a tie is recorded as long as either side of the dyad reports a tie.

Analyze the sociomatrix data using a spreadsheet program or software. The basic measures of indegrees and outdegrees are simple to calculate row- or column-sums. Density and most of the other measures can also be calculated using LOTUS 1-2-3. We recommend LOTUS 1-2-3 over Microsoft EXCEL because LOTUS 1-2-3 offers a very easy to use matrix multiplication command. Or, use a social network analysis program like UCINET. Determine the numbers of components, cliques, or subgroups. Identify major sources and major sinks. Identify transmitters, brokers, articulators. Aggregate the elemental data into sectors using UCINET’s CONCOR algorithm. Assign ties using the *sinks substitute* or *sources substitute* criteria (introduced in this paper); generate the blockmodels and reduced digraphs. Apply the “fracture” and/or “efficient path” tests introduced in this paper to identify the *keystone sectors*. Note that we used LOTUS 1-2-3 to assign blockmodel ties and to conduct the fracture and efficient path tests. Obviously, those are not available on UCINET because we developed those procedures for this project.

Strengths and Weaknesses

We have also raised many caveats. Dichotomous data imply that all interactions are of equal significance. This assumption is acceptable for non-rival interactions, but it is less appropriate for rival transactions, such as those concerning money. It is possible that a sector with a few large links may be much more critical than the sectors with many (smaller) links; this methodology will fail to identify those sectors as key.

Also, the articulate roles of some entities are exaggerated when analyses are based on measures for which symmetry is imposed. When we ignore the direction of a relation, we incorrectly assume that an exchange is reciprocated when it may not be. Other potential pitfalls may arise from blocking and tie assignment procedures. The patterns of ties to and from a block depend on the entities in the block, so the blocking procedure matters. We also showed that different criteria for tie assignment give a different block model. In the Towertown application, we are just lucky that the results of our tests for "keystoneness" are the same regardless of the procedure used for tie assignment. The α-density network is just as sensitive to the excision of banks as our sinks/substitute networks are. But with other data, the results of the *fracture* and *efficient path* tests for keystoneness may be different across blockmodels developed using different criteria.

By replicating these methods and analyzing the network structure of other communities we may learn how sensitive the approach is to these potential pitfalls. Meanwhile, it is clear that the approach can offer significantly new types of insight. Our finding that financial intermediaries play a critical role in a community is an example of one of those insights. Previous studies in the critical sector tradition, based on material input-output relationships, have ignored the banking sector (along with government entities and voluntary associations). This is because input-output data concern only current account transactions. We believe that in some communities, public service providers, private voluntary associations, or other non-business entities may also be key. One lesson is that many types of interactions and many types of entities may be very important, not just business interactions. Here we have demonstrated a method that can be used to quantify and analyze almost any kind of interaction information between any kinds of entities.

Results and Implications

So far we have summarized this project's contribution to meeting TVA Rural Studies' mission area of "finding new ways to describe and analyze rural economies." In the introduction, we suggested that "to efficiently enhance entrepreneurial/business activity, an agency may wish to target public support to the *keystone sector*." We have shown that the "Keystone Sector ID" method identifies different sectors that can be identified using the prevailing I-O based "critical sector" or traditional "industrial targeting" approaches.

The outcome of all the analyses of the Towertown community data is the robust finding that *banks are a keystone sector*. The banking sector appears to be key according to all the various graph-theoretic measures of centrality, prestige, connectivity, and the sensitivity of the network to their excision. At the individual level, banks were identified as the cut-points, and their excision isolated various voluntary organizations from the network, without disrupting the other ties. At the blockmodel level, banks were shown to play a critical role as a group. Their excision from the blocked network also left voluntary associations isolated without disrupting other ties.

Now that we have a way to identify the "Keystone Sector" in one community, how might we proceed to "enhance entrepreneurial/business activity" or "support innovative community change," the other two TVA Rural Studies mission areas? In our opinion, *we must first apply the Keystone Sector ID procedures to many small communities before concluding that any one sector (such as banks) is "the keystone" in small communities* in general. The testable (alternative) hypotheses include: communities that do not have a bank or S&L are not fully-connected.

Furthermore, communities that are not fully-connected may have (hypothetically) fewer viable voluntary associations. Can we say that disconnected network communities have lower levels of "social capital?" We expect to find that property values in such communities do not rise. In contrast, we expect property values in fully-connected communities with more than one individual actor in their keystone sector (a competitive rather than monopolized keystone sector) to rise. We need to replicate the Keystone Sector ID study many times on different rural communities before we can draw inferences about what is the "keystone sector" in general. Then we should proceed to test for associations between community development outcomes and network patterns.

In closing, we hope that this report inspires other researchers to apply our "Keystone Sector ID" method to analyze other communities. We look forward to collaborating on ways to (1) compile single community network studies into a sample so that we can draw inferences from a sample of communities, and (2) test for the dependence of rural development outcomes on network structure.

ENDNOTES

[1] A *multiplier matrix* is calculated from an industry x industry transactions matrix in three steps as follows. First, divide the transaction cells by the column totals. This gives a matrix of sectoral expenditure shares. Second, subtract this matrix from the Identity matrix. Third, invert the subtrahend. This inverted matrix is the multiplier matrix.

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Appendix I: Entities in "Towertown"

1-Farm Bureau
2-Farm Equip. Co.
3-Clothing Mfg. Co.
4-Farm Supply Co.
5-Mechanical Co.
6-Electric Equip. Co.
7-Metal Products Co.
8-Music Equip. Co.

9-Chamber of Commerce
10-Bankers' Association

11-First Towertown Bank
12-Towertown Savings and Loan
13-Bank of Towertown
14-Second Towertown Bank

15-Brinkman Law Firm
16-Cater Law Firm
17-Lenhart Law Firm

18-County Bar Association
19-Towertown Board of Realtors
20-Towertown Small Bs. Association
21-Municipal Employees Union 1
22-Municipal Employees Union 2
23-Teachers' Union
24-Central Labor Union

25-City Council
26-City Manager's Office
27-County Board
28-Fire Department
29-Human Relations Commission
30-Mayor's Office
31-Police Department
32-Sanitary District
33-Streets and Sanitation
34-Park District
35-Zoning Board
36-Democratic Committee
37-Republican Committee

38-League of Women Voters

39-The Towertown Newspaper
40-WTWR Radio Station

41-Towertown Public Hospital Board
42-Towertown Public Hospital
43-County Medical Society
44-County Board of Mental Health
45-County Board of Health
46-County Health Service Center

47-State Highway Authority
48-Kiwanis Club 1
49-Kiwanis Club 2
50-Rotary Club
51-Lions Club
52-United Fund

53-School Board
54-Towertown High School
55-Towertown Parent-Teacher Association
56-Towertown Community College
57-State University

58-Association of Churches 1
59-Association of Churches 2
60-St. Hilary's Catholic Church
61-First Baptist Church
62-First Church of the Light
63-First Congregational Church
64-First Methodist Church
65-Unity Lutheran
66-University Methodist Church

67-State Department of Public Aid
68-County Housing Authority
69-Family Services
70-State Employment Services
71-YMCA
72-Mental Health Center
73-Towertown Youth Services Bureau

Appendix II: CONCOR Results

Block 1: Farm Bureau, St. Hilary's Catholic Church, University Methodist Church, Association of Churches 1, First Congregational Church, and First Methodist Church

Block 2: County Medical Society, County Board of Mental Health, TT Public Hospital Board, County Housing Authority, TT Public Hospital, State Employment Services, State Department of Public Aid, Mental Health Center, and County Board of Health

Block 3: TT Community College, State University, TT High School, and TT Savings and Loan

Block 4: YMCA, United Fund, County Health Service Center, Family Services, and Brinkman Law Firm

Block 5: First Church of the Light, League of Women Voters, First Baptist Church, School Board, TT Small Business Association, Bankers Association, and Chamber of Commerce

Block 6: Kiwanis Club 1, Kiwanis Club 2, Rotary Club, Lions Club, TT Parent Teacher Association, and Park District

Block 7: WTWR Radio Station, Association of Churches 2, City Manager's Office, TT Newspaper, City Council, County Bar Association and Cater Law Firm

Block 8: Human Relations Commission, Fire Department, Police Department, Sanitary District, Mayor's Office, County Board, and Zoning Board

Block 9: Farm Equip Co., Clothing Mfg. Co., Farm Supply Co., Mechanical Co., Electric Equip Co., Metal Products Co., and Music Equip Co.

Block 10: Unity Lutheran Church

Block 11: First TT Bank, Second TT Bank , and Bank of TT

Block 12: Streets and Sanitation, State Highway Authority, TT Board of Realtors, and Lenhart Law Firm

Block 13: Democratic and Republican Committees

Block 14: Municipal Employees Union 1 and Teachers' Union

Block 15: Municipal Employees Union 2 and Central Labor Union

Appendix III: Blockmodel Sectors

Sector 1: BANKS:

Block 11: First TT Bank, Second TT Bank, Bank of TT, and TT Savings and Loan

Sector 2: BUSinesses:

Block 9: Farm Equip Co., Clothing Mfg. Co., Farm Supply Co., Mechanical Co., Electric Equip Co., Metal Products Co., and Music Equip Co.

Not from intact CONCOR blocks: Lenhart Law Firm, Brinkman Law Firm, Cater Law Firm, WTWR Radio Station, TT Newspaper

Sector 3: GOVernment agencies

Block 2: County Medical Society, County Board of Mental Health, TT Public Hospital Board, County Housing Authority, TT Public Hospital, State Employment Services, State Department of Public Aid, Mental Health Center, and County Board of Health.

Block 3: TT Community College, State University, TT High School

Block 8: Human Relations Commission, Fire Department, Police Department, Sanitary District, Mayor's Office, County Board, and Zoning Board

Not from intact CONCOR blocks: County Health Service Center, Family Services, Streets and Sanitation, State Highway Authority, City Manager's Office, City Council, and Park District

Sector 4: VOLuntary associations:

Block 1: Farm Bureau, St. Hilary's Catholic Church, University Methodist Church, Association of Churches 1, First Congregational Church and First Methodist Church

Block 5: First Church of the Light, League of Women Voters, First Baptist Church, School Board, TT Small Business Association, Bankers Association, and Chamber of Commerce

Block 6: Kiwanis Club 1, Kiwanis Club 2, Rotary Club, Lions Club, TT Parent Teacher Association

Block 10: Unity Lutheran Church

Block 13: Democratic and Republican Committees

Block 14: Municipal Employees Union 1 and Teachers' Union

Block 15: Municipal Employees Union 2 and Central Labor Union

Not in an intact CONCOR block: YMCA, United Fund, Association of Churches 2, County Bar Association, TT Board of Realtors

CONCOR groups that were split: Blocks 4, 7, and 12

igure 1. Towertown
nformation Flows