ABSTRACT

MATRIX MULTIPLICATION IN THE STUDY OF INTERPERSONAL COMMUNICATION

by Lytton L. Guimaraes

A major argument of the present thesis is that communication research has overemphasized individual behavior, and neglected communication interaction processes. One alternative to focusing on individuals as separate units, is to change to networks of relations among individuals as units of analysis. Under the latter perspective, the individual is treated as part of a larger system, rather than as an isolated or independent unit.

Two major data-gathering techniques are appropriate for relational studies: (1) the "snowballing" technique, and (2) the "saturation" sample. Sociometric-type questions, as a technique of measurement, allows the identification of networks of communication surrounding each respondent.

The unit of analysis in relational studies may be a communication system. A communication system embraces subsystems as dyads, chains, cliques, and subgroups. In addition, it contains such elements as communication leaders, liaisons, and isolates.

The analysis of relational data, with focus on a communication system (or on any of its subsystems) may be performed with the use of (1) charts, such as sociograms, digraphs, and sociomatrices, or (2) by means of matrix multiplication.

The major objective of the present thesis was to examine the relative merits of the matrix multiplication approach (as compared to

the sociogram, the digraph, and the sociomatrix) in the analysis of relational data.

Another objective of the present study was to illustrate the use of the matrix multiplication technique with relational data from two Brazilian communities.

One general conclusion that can be drawn from the present study is that, for relational analysis, the matrix multiplication approach has advantages over merely representational techniques (e.g., sociograms, digraphs, sociomatrices). And importantly, the use of the matrix multiplication approach does not exclude the use of one or more of the three other techniques.

When using the matrix multiplication approach, different researchers can manipulate the same relational data, and the results yielded will tend to be similar. Simple diagrammatic presentations, on the other hand, may provide different visual images, depending on the way they are constructed. The interpretation of the results yielded by the matrix multiplication approach is relatively simple, whereas diagrams may become cumbersome and difficult to interpret, especially when a relatively large sample size is involved. Another feature of the matrix multiplication approach is objectivity in interpretation, while representational devices, often built on a trial basis, might not be as free from error.

The application of the matrix multiplication technique to relational data obtained in a "modern" and a "traditional" community in Minas Gerais, Brazil, lends support to the foregoing conclusions. The method allows the identification of formally defined structures of

the communication system, as well as the analysis of indirect relations. As a data-reduction technique, the matrix multiplication approach allows the formation of indices and process variables, which in turn allow, when dealing with relational data, a shift in the focus of analysis: from the individual to dyads, cliques, subgroups, or larger systems. It is clear, however, that for certain situations (i.e., visual effects), a combination of the matrix multiplication approach and diagrams is desirable.

When dealing with relational data, the matrix multiplication approach produces a series of indicators of the patterns of interconnections of a communication system (e.g., number of isolates, dyads, subgroups, cliques, etc.). Some of these indicators seem so interrelated that it becomes difficult to determine, at this point, whether they are really independent estimates. An important task for future research is to further examine these indicators with the purpose of reducing them to valid and reliable indices.

Another research realm that requires attention relates to conceptual and theoretical problems. A variable that needs further theoretical (and methodological) consideration is communication integration. The idea that the diverse parts of a communication system normally cohere in some determinate fashion may prove useful in different contexts. It may help to explain, for example, how members of a social system accept, reject, or modify innovations which are diffused from other systems. Administrators and change agents may be guided by the concept of communication integration in their effort toward introducing innovations into "less developed systems." Communication integration has not been studied as a major variable, but recent developments in modern society and in behavior research point to the salience of the concept.

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Director of Thesis

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TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Characteristics of Communication Research

Over the past two or three decades, there has emerged a focus of research and theory in social science with communication as its center. This work has covered a wide range of interests. Many communication, or communication-related questions, have attracted the attention of numerous social scientists, with the result that a voluminous communication research literature is today identifiable.

One shortcoming of this literature, as perhaps of social science research literature in general, is the fact that it is largely limited to demonstrating the importance of one factor, or variable, in affecting one or more other factors, or variables. Lazarsfeld and others (1948), for example, demonstrate in their now-famous voting study the importance of personal influence in the process of political decision-making; similarly, Levin's (1943) classic study comparing the efficacy of a lecture and a group discussion in changing housewives' opinions about new foods, shows the relevance of group discussion in instituting change.

One might argue that these are pioneer efforts and are not indicative of present trends in communication studies. But the accumulated research reports in the area of the diffusion of innovations, for example, also reflect this tendency toward the categorization of concepts as dependent and independent (Rogers, 1962)* In fact, the list could be extended indefinitely, and many examples could be drawn from all areas of communication research.

It might be said that most of what is today generally regarded as communication research is in the variable-searching stage, in that it is concerned with demonstrating the existence of bi-variate relationships. This condition is apparently part of what Coleman calls the "pre-mathematical state" in research: "A casting about, identifying the outlines of the phenomena to be studied, searching for the best concepts by which to represent the phenomena" (Coleman, 1960, p. 11).

Apart from this emphasis on demonstrating the existence of relations, rather than their precise form, this communication research literature also reflects a general concern with single (zero-order) relationships between variables, that is, the effect of X upon Y, rather than with their functional interdependence. Although single relationships may eventually form a conjunction of interconnected generalizations, and perhaps become a theory, taken in isolation they can be viewed only as single quantitative statements.**

The tendency of showing the existence of relationships and the general concern with zero-order analysis, coupled with the problem of

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*Since the publication of Rogers' book, in which more than 400 diffusion studies, of different traditions, are examined and synthesized, over 600 new research reports have been incorporated in the Diffusion Documents Center at Michigan State University. Most of these 1,000 empirical studies concern the analysis of pairs of independent and dependent variables. See Rogers (1967).

**And, as such, of relatively lower value.

adequate measurement, have undoubtedly inhibited certain developments in communication research. But perhaps an even more serious obstacle to the theoretical and methodological development of communication research is the tendency to study individual behavior, often incorrectly disguised as communication behavior.

Many studies which are currently labeled as "communication" are in actuality studies of individual behavior. Among these we can include most of those group-centered investigations in which the group is looked upon not as a system of communication behavior about which generalizations or theories are to be developed, but simply as a context within which the individual acts. The group is often used as a manipulable social stimulus, and the focus of concern is upon the behavior of the individual within it. Festinger and Carlsmith's (1959) study, in which the amount of external justification (money) received by the subjects to lie about the performance of a dull task is related to cognitive dissonance, is an example of this use of the group. The series of studies which followed Festinger and Carlsmith's, as well as the so-called "fear appeal" experiments are also examples of hundreds of such investigations in which the group is "controlled" by the experimenter.* Reports of these investigations show that the researcher is in fact studying individual behavior in a group situation, rather than group behavior (or interpersonal relationships) as such. These experiments may develop generalizations about the behavior of an

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*Some of the studies on "insufficient justification" are: Brehm and Cohen (1962); Aronson and Carlsmith (1963); Nuttin (1964); Janis and Gilmore (1965); etc. Examples of "fear appeal" studies are: Janis and Feshbach (1953) and Janis and Milholland (1954).

individual under certain social conditions, but leave unexamined the behavior of the social system which constitutes these conditions.

Investigations such as these can of course contribute to the development of models of individual behavior within a social context, but they reflect a traditional psychological tendency toward a monadic view of man, that is, the tendency to view the individual in isolation, out of his sociocultural context, or to use Watzlawick and others' notion, out of his "communication nexus" (Watzlawick, 1967, pp. 21-22). Studies of this nature, therefore, can serve only as one component of communication models. This theoretical orientation might explain the reason why most communication models imply linearity or unidirectionality (e.g., the Westley-MacLean model)* in that they seem to limit the study of communication as one-way phenomenon (from source to receiver), neglecting to look at communication as an <u>interaction</u> process.

A complete communication model must deal with a system of behavior in which the individual is only a part. To quote Birdwhistell: "An individual does not communicate; he engages in or becomes part of communication . . . . Communication as a system, then, is not to be understood on a simple model of action and reaction. . . . As a system, it is to be comprehended on the transactional level" (Birdwhistell, 1959, p. 104).

Watzlawick and others (1967) realize these problems. They argue that communication is a process of <u>symmetrical</u> and <u>complementary interaction</u>, depending on whether it is based on equality or difference.

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*See Westley and MacLean (1957 and 1965).

If two partners mirror each other's behavior, their interaction is based on equality, and is therefore symmetric. If one partner's behavior "complements that of the other, forming a different sort of behavior Gestalt," their interaction is complementary, i.e., based on maximization of differences (Watzlawick and others, pp. 68-69). The important point in this symmetry-complementarity paradigm is the recognition that the individual's positions are merely variables whose meaning emerges only in relation to each other (Watzlawick and others, 1967, p. 71).

In a recent paper Rogers and Jain (1968) bring these same problems to the realm of diffusion research. In their opinion, one of the "biases" implicitly adopted by diffusion researchers, as imposed upon them by historical developments of the field, is their focus on "individual, intra-personal variables, largely to the exclusion of social structural variables." They claim that because the individuals were generally their units of response, diffusion researchers erroneously assumed that the individual also had to be the unit of analysis.

Needed Emphasis on Relational Analysis

As early as a decade ago, Coleman (1958) urged sociologists to abandon their concern with individuals as separate and independent units. He proposed a change to networks of relations among individuals as units of analysis. Rogers and Jain (1968) subscribe to these ideas and go beyond to suggest that "It is entirely appropriate to utilize relationships, pairings, chains - as our units of analysis in diffusion inquiry, rather than individuals."

These pleas in favor of relational studies have so far received conspicuously little attention. One explanation for this neglect, Coleman (1958) claims, lies in the data-gathering techniques of most survey research: random samples, which only by accident included "two persons who were friends," interviews conducted with one individual "as an atomistic entity," and responses coded "onto separate IBM cards, one for each person" (Coleman, 1958).

Years ago, the use of survey research methods might have been as important a factor as Coleman indicates. But most recently, "even with the use of survey methods, . . . various techniques of measurement, data gathering, and data analysis can be utilized to provide focus on relationships rather than on individuals" (Rogers and Jain, 1968).

More specifically, the incorporation of sociometric-type questions into survey research, as a technique of measurement, allows the identification of networks of communication surrounding each respondent. Responses to such questions as: "Whom do you visit more frequently?" or, "When you need advice on such-and-such a problem, whom do you usually seek?" - can be aggregated over each system (e.g., a group or a community) to characterize its communication patterns. One may also single out subsystems such as dyads, chains, cliques, and so on.

Coleman discusses in some detail several sampling procedures appropriate for what he calls "relational analysis."* One is the so-

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*Relational analysis may be defined as a methodological approach (to survey research) in which each individual respondent sees himself as a part of one or more social systems. Thus, the respondent is not treated as an isolate or independent unit, but as an called "snowballing" technique, which consists essentially of interviewing first a small sample of persons, then asking these persons to indicate their best friends, for example, and then asking those so named who their friends are, interviewing them, and so on. Another approach, which Coleman calls "saturation sampling," is to interview everyone within a relevant system.

The important point here is that the individual is treated as part of a larger system, and not as an isolated or independent entity. And this is done via the formulation of the question, sampling, and in the subsequent analysis of the data.

The analysis of relational data has itself two important and interdependent aspects: one refers to the unit or level of analysis, and the other to the means or techniques of analysis.

The Unit of Analysis in Relational Studies

The unit of analysis may be any of the aggregated systems referred to previously, that is, a dyad, a chain, a subgroup, a clique, or the communication system as a whole.

1. A dyad is the smallest analytical subsystem within the communication system; it consists of two persons mutually engaged in interaction. This interaction may be symmetrical* or complementary, as long as it satisfies the criterion of reciprocal orientation.

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element in a larger whole (a relationship).

*Symmetrical interaction is that based on equality of behavior. Complementary interaction, on the other hand, is based on maximization of differences (see Watzlawick and others, pp. 68-69).

2. A chain refers to n numbers of participants of a communication system who are interconnected at a given point in time, by a given communication input (e.g., a message).

3. A subgroup consists of two or more individuals linked mainly--but not exclusively--by unreciprocated relations.

4. A clique is a subsystem (of the communication system) in which at least three members mutually interact.

5. A communication system may be part of a larger system, such as a group, a community, or a nation. It is the largest identifiable communication unit within a larger system. It therefore embraces such communication subsystems as the dyad, the chain, the clique. Furthermore, it contains such elements as communication leaders, liaisons, and isolates.

(1) A communication leader is a person who is looked upon by his peers as both a receiver and a source of communication. For this reason, he is sought by other members of the communication system with relatively greater frequency than most elements.

(2) A liaison is a person who interconnects two or more subgroups or cliques in the communication system.*

(3) An isolate is a person who neither seeks nor is sought by any other member of the communication system.

*Jacobson and Seashore (1951) initiated studies on the role of liaison individuals within a social structure. Weiss and Jacobson (1955 and 1964), and Schwartz (1968) have also studied liaison roles within formal organizations.

The Techniques of Analysis in Relational Studies

The analysis of relational data, with focus on any of the subsystems defined in the preceding paragraphs (i.e., a dyad, a chain, a clique, a communication system) may be performed with the use of (1) charts or diagrams such as "sociograms," "digraphs," or "sociomatrices," or (2) by means of matrix multiplication. Each of these two major approaches, although not necessarily mutually exclusive, has its advantages and its limitations. It may be relatively easy, for example, to plot a sociogram, a digraph, or a sociomatrix of the communication patterns of a small group of 10 or 20 persons, but be very difficult to comprehend the data contained in them. Matrix multiplication, on the other hand, is one of a number of possible approaches to "partial mathematization" of communication data. As a method of data-reduction, it allows the formation of indices and of process variables, which in turn makes possible, when dealing with relationships, a shift in the unit of analysis: from individual to dyad, groups, and so on.

Objectives of the Present Study

The major objective of the present study is to examine the relative merits of the matrix multiplication technique in the analysis of certain specified communication relations among members of a social system. For this purpose, a comparison is made with the alternative techniques already mentioned (the sociogram, the digraph, and the sociomatrix).

Another objective of the present study is to illustrate the use of the matrix multiplication approach with relational data from two

Brazilian communities. The relations dealt with are essentially of the all-or-none type, or two-valued relations, as illustrated by the following examples:

1. Communication or friendship relations: Individual i does or does not choose individual j as a friend or a person with whom he interacts.

2. Influence or dominance relations: Individual i does or does not choose j as an influential person in the social system.

Although the matrix multiplication approach has been used in the past, especially in social psychological research, some of its crucial aspects remain largely unclear.* Those who have made use of this approach apparently do not deem it necessary to discuss in detail the operations and procedures involved, or else they maintain their discussion at such a level of mathematical sophistication that many readers or potential users of the method seem to feel alienated from its "mathematical complexities," with the result that its application remains largely restricted to mathematically-inclined researchers.

We aim in the present thesis to examine in detail some of these unclear problems and attempt to show that the matrix multiplication approach is rather simple, and can be appropriately handled with a minimum knowledge of matrix algebra.

The assumption is that studies such as the present have

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*Lin (1968) used this technique in a study dealing with innovations in school systems. As in previous reports, however, he does not discuss in detail the procedures involved.

theoretical and methodological consequence. One potential methodological contribution is a refinement of procedures for the treatment of relational data. Methodological improvements may, on the other hand, contribute to the development of a theoretical framework capable of more adequately handling certain types of communication data. The development of both theoretical and methodological aspects may in turn contribute more fully to the dissemination of knowledge derived from communication research, assuming that the more sophisticated the theoretical and methodological tools, the more reliable they will be. To paraphrase Kurt Lewin: Nothing is more practical than a good theory. A good theory rests, however, on equally good methodology.

CHAPTER II

METHODS OF RELATIONAL ANALYSIS

The purpose of this chapter is to briefly describe the most commonly used approaches to relational analysis, and thus establish a basis for comparison with the matrix multiplication technique, which is examined in the next chapter. Sociograms are described first, then digraphs, followed by a brief account of uses of "who-to-whom" or sociomatrices. The last section of the present chapter deals with some of the relationships between digraphs and matrices.

The Sociogram

Traditionally, relational data derived from sociometric-type questions have been presented by means of graphs or diagrams, such as the one in Figure 1.

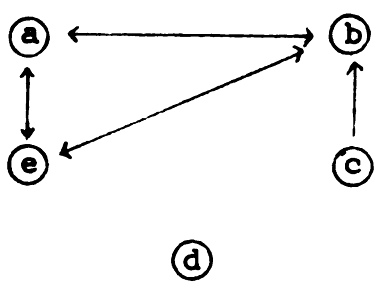

Figure 1. The influence structure of a five-member hypothetical group, as represented by a sociogram.

Such graphs, called sociograms, have been used to illustrate numerous kinds of structural or relational interconnections within a group. The circles represent group members (here, a, b, c, d, and e); the choices or nominations among them are represented by the directed lines, and the arrowheads indicate the direction of the relationship. The line between c and b, for example, usually means that c chooses b as a friend or influential. In some diagrams the direction is reversed, however, for influence relationships. Unless otherwise specified, all arrows appearing in a single sociogram represent the same type of relation. This means that usually a single type of interconnection (e.g., influence) within the group is represented in any particular diagram.*

Assuming that the diagram in Figure 1 represents the influence structure of a five-member hypothetical group, one may intuitively say that since b's influence domain includes three of the other four members of the group, he might be a leader, or an influential person in the group.** On the other hand, d, who neither chose nor was chosen by any other group member, might be an isolate in the group influence structure.

By further examining the sociogram in Figure 1, we notice that

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*The "sociometric approach" to group analysis was originated by Moreno (1934). For a review of the remarkably large quantity of research conducted within this orientation in a relatively short time, see Lindzey and Borgatta (1954). Much of Moreno's work and that of his associates has been summarized in Moreno (1960). A recent discussion on sociometry (procedures for data collection, applications, etc.) may be found in Borgatta (1968). Sociometry and The International Journal of Sociometry, founded by Moreno, are journals dedicated mostly to this, or closely related, areas of research.

**A person's influence domain is the number of individuals in his social system whom he influences directly or indirectly.

one-step symmetrical connections exist between persons a, b, and e. Taken together, these three sets of relations form a clique, defined as a system in which at least three members have reciprocal interaction.* Taken individually, each of the three sets of symmetrical relations (i.e., a↔b, a↔e, and b↔e) forms a dyad, defined as two persons mutually engaged in interaction.

A sociogram is therefore a representational device used to illustrate certain types of relations (usually two-valued) between pairs of individuals in a group. As such, sociograms have been widely used in social psychology and sociology. Often, however, these diagrams become confusing to the reader. When the number of elements in a group is relatively large, or when the number of choices allowed each respondent is increased, the structure of relations tends also to increase in complexity, with the result that the pictorial representation of these relationships may become cumbersome and difficult to comprehend. In addition, certain graphic representations may be rather misleading, as can be seen by the example provided in Figure 2.

Only through careful examination will one perceive that the four sociograms (a, b, c, and d) in Figure 2 represent the same structural relations. This is so especially because there are no specified standard rules for the construction of sociograms. The location of the circles representing each group member is arbitrarily arranged. In fact, different researchers using the same data may build as many

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*Festinger and others define this particular type of subgroup as "an extreme instance of clique formation within a group," in that it is composed of three individuals "all of whom choose each other mutually" (Festinger and others, 1950, p. 144).

different sociograms as there are researchers.

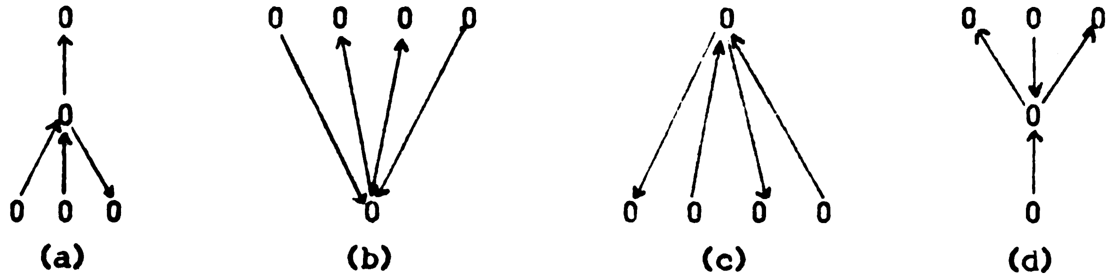

Figure 2. Example of four different sociograms representing the same structural relations in a hypothetical five-member group.

Early attempts to deal with this problem, so as to make sociograms more understandable and more useful for the analysis of social structures, have resulted in several alternative techniques, but satisfactory operating rules for the construction of such diagrams have yet to be developed.

Northway (1940 and 1960) proposes a system called a target sociogram which emphasizes "choice status," indicated by concentric circles, with the person receiving the highest number of choices placed at the center of the circle. Patterns of relationships are shown in the usual way. Powell (1951) suggests the use of symbols of different sizes to differentiate people on the basis of the number of sociometric nominations they receive. Proctor and Loomis (1951) make use of physical distance between points on the sociogram to represent choice distance between persons (e.g., mutual choice, very close; mutual rejection, very distant, etc.). Still other devices are offered by different authors, but the fact remains that the analytic utility of the sociogram appears to be limited, since such analyses are usually restricted to descriptive statements.*

Students of graph theory have undertaken systematic investigations of the properties of diagrams, using terms such as simplexes (topology), circuit diagrams (physics and engineering), organizational structures (economics), digraphs, etc. The latter term was proposed by Pólya and is used by Harary and others (1965). The next section of the present chapter is a brief discussion of digraphs, and their potential use in relational analysis.

The Digraph

The theory of graphs, or graph theory, deals with abstract configurations called "graphs."** A graph consists of certain points, a, b, c, and d, called its vertices, and certain line segments connecting

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*Spilerman (1966) suggests a method for analyzing sociometric information using a mutual choice sociomatrix. According to Spilerman, the connection matrix developed by this routine can be easily transformed into a sociogram. A computer program which constructs the matrix directly from sociomatrix data is mentioned by Spilerman, but details are not given.

**The first paper on graph theory was written by the famous Swiss mathematician Leonhard Euler (1707-1783) and it appeared in 1736. One of the first systematic treatments of graph theory was provided by König (1936). Initial applications of the theory were, however, "little or nothing more than giving names to points, lines and particular configurations of points and lines" (Coleman, 1964, p. 1043), with perhaps little interest for the social scientist. Subsequent works have gone beyond this initial state, as exemplified by the works of Berge (1962) and Flament (1963) in France, and Ore (1962; 1963), Busacker and Saaty (1965), and Harary and others (1965) in the United States. In mathematics graph theory is classified as a branch of topology; but it is also strongly related to algebra and matrix theory. Graph theory derives, in fact, from theories about nets and relations. A net consists of a finite set of points together with a finite set of lines, where each line is an ordered pair of points. A relation is a net in which no two lines are parallel (Ore, 1963; and Harary and others, 1965).

vertices such as ac, db, etc., which are called the edges of the graph (Ore, 1963, p. 5). There are different types of graphs which turn up in many uses of graph theory. One type of graph has a direction or orientation associated with each one of its edges. This special type of graph is generally called a directed graph (Ore, 1963; Busacker and Saaty, 1965), or simply a digraph (Harary and others, 1965). A digraph consists therefore of points and directed lines.*

The primitive or undefined terms of the axiom system for digraphs are the following:**

Primitives:

P_1: A set V of elements called points.

P_2: A set X of elements called lines.

P_3: A function f whose domain is X and whose range is contained in V.

P_4: A function s whose domain is X and whose range is contained in V.

The axioms of a diagraph are:

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*The term network is frequently used instead of graph or digraph, especially when quantitative characteristics are imparted to the points and lines, in addition to the purely structural relationships that are the defining characteristics of a digraph. One speaks, for example, of electrical networks, and flow networks, in which quantitative measures of energy, and flow, respectively, are associated with the edges (Busacker and Saaty, 1965, p. viii).

**Unless otherwise indicated, the remaining discussion of graph theory, as well as the definitions given hereafter, are based on Harary and others (1965) and Flament (1963).

A_1: The set V is finite and not empty.

A_2: The set X is finite.

A_3: No two distinct lines are parallel.

A_4: There are no loops.*

In discussing digraphs, points are sometimes referred to by the notations v_1, v_2, ... v_p, and sometimes by letters such as u, v, w. In the present thesis we will simply use a, b, c, etc. The lines of a digraph are frequently indicated by x_1, x_2, . . . x_q. A line, in terms of its two points, is indicated by v_1v_2 for a line from v_1 to v_2 or uv for a line from u to v.

An example of a simple digraph with its customary notation is provided in Figure 3. The set V has three points (p = 3) and the set X contains four lines (q = 4). The three points are denoted a, b, c and the four lines are: x_1 = ab; x_2 = ba; x_3 = ac; x_4 = ca.

Assuming that the digraph (D) in Figure 3 represents a friendship structure, one of its interpretations might be the following: the

D:

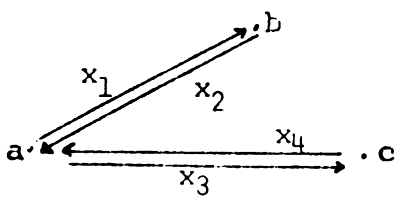

Figure 3. Example of a digraph with its customary notation.

*Two lines x_1 and x_2 are parallel if $f(x_i) = f(x_j)$ and $s(x_i) = s(x_j)$. A line x is called a loop if $f(x) = s(x)$, i.e., if it has the first and the second points.

points a, b, c represent three persons and each line indicates friendship relations between them. Since there are no lines joining points a and c, one may infer that the two persons represented by these two points are not friends. On the other hand, the lines connecting a and b and a and c illustrate dyadic interactions, meaning that person a has b and c as mutual friends.

The theory of directed graphs is concerned with the abstract notion of structure. As such, it deals with patterns of relationships among pairs of abstract elements. Thus, the theory *per se* makes no reference to the empirical world. As shown in many studies, however, it can serve as a mathematical model of the structural properties of relationships among pairs of elements, since it provides concepts, theorems, and methods appropriate to structural and relational analysis.

Harary and others (1965, p. 3) give three principal benefits which in their opinion the researcher may gain from employing digraph theory in his treatment of structural or relational data:

1. His vocabulary for describing empirical structures is enriched by useful new terms having precise meanings: the language of digraphs contains a large number of concepts which refer to relatively complex structural properties.

2. Digraph theory and associated branches of mathematics provide techniques of computation and formulas for calculating certain quantitative features of empirical structures.

3. The axioms for digraph theory lead to an extensive body of logically derived statements: each of these statements or theorems becomes a valid assertion about any empirical structure that satisfies

the axioms of digraph theory.

Perhaps one of the more interesting applications of digraph theory (from the social scientist's point of view) is in connection with the so-called balanced principle of social psychologists. As proposed by Harary (1954; 1955; 1959a), whenever the relations between a dyad can be viewed as positive or negative, their balance or imbalance can be determined. This procedure is accomplished by multiplying the signs around each cycle of a digraph.* The relational structure will be balanced if the product is positive, and unbalanced if negative. Flament (1963) developed this notion further. With the use of lattices, he determined the minimum length path through which an unbalanced graph can become balanced by successive changes of links.**

When compared to merely representational devices or descriptive techniques such as sociograms (as treated in the present study), digraphs contain many more mathematical properties, and therefore offer considerably greater possibilities for mathematical analysis of structural and relational data. Nonetheless, some authors believe (e.g., Berge, 1962; Coleman, 1964) that the operations yet available in this branch of mathematics are rather weak. The whole approach needs to be further developed in order that it may be usefully applied in several different domains of social and behavior research. One of its obvious

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*A cycle of a digraph consists of a nontrivial path (i.e., a path consisting of more than one point) together with a line from the terminal to the initial point of the path (Harary and others, 1965, pp. 39-42).

**A finite ordered set is a lattice if every one of its parts possess a superior limit and an inferior limit. The superior limit of a subset of parts is their union; the inferior limit is their intersection (Flament, 1963, p. 14).

limitations (as that of the sociogram) has to do with the number of elements in the group under consideration. The larger the N, or sample size, the more complex the representation of its structural relations.

It was perhaps the recognition of some of these difficulties that led students of graph theory to expand their interest in other branches of mathematics. Matrix algebra has an especially close relation to the theory of directed graphs. In fact, one of Flament's main interest is what he calls l'analyse grapho-matricielle des structures or the matrixgraphic analysis of structures (Flament, 1958b, p. 130). Berge (1962) and Harary and others (1965) also deal extensively with the relationships of graph theory to matrix algebra. Many of these important relationships cannot be examined in the present study, but at least some will be reviewed briefly in the last section of the present chapter.

The Sociomatrix

Forsyth and Katz (1946 and 1960) developed an alternative procedure for handling sociometric data, the sociometric matrix or simply sociomatrix. This is a matrix of N by N dimensions corresponding to a group of N persons. Conceptually similar to the sociogram, the sociomatrix differs mainly in the ease with which certain types of data can be handled. Forsyth and Katz's (1946 and 1960) idea is simply to list the persons in the system along the rows and the columns in the same order. The row corresponds to the persons making the nominations or sociometric choices, and the columns to the persons receiving the nominations. The choices made by any of the group members are then entered in the appropriate cells. A plus (+) sign is used for positive choices (i.e., to indicate that a person chooses another), a minus (-) for negative choices or rejections, and blanks for indifference or no mention. The cells along the principal diagonal correspond to self-choices and may be filled in with x's. Figure 4 illustrates the form in which the data can be recorded. It is read horizontally, thus: a chooses b and e, is indifferent to c and

		Nominees				
		a	b	c	d	e
	a	x	+		-	+
	b	+	x	-		+
Nominators	c	+	+	x	+	-
	d		-	-	x	-
	e	-	+	+		x

Figure 4. Example of a sociomatrix with a hypothetical five-member group.

rejects d. Column one is read thus: a is chosen by b and by c, and rejected by e, whereas d is indifferent to a.

Forsyth and Katz (1946 and 1960) suggest a few manipulations in the original matrix to produce a new matrix which will exhibit the group structure in a standard form. These manipulations consist of rearranging the position of group members in such a way that the new matrix will show (in a cluster along the main diagonal) the persons who have positive mutual choices, and those who do not choose each other as relatively separated. The tendency is for the blocks of minus signs to appear at the upper righthand and lower lefthand corners of the matrix, while the genuine isolates will tend to appear at or near the center of the matrix.

Variations of the sociomatrix have been used by different researchers. Bales' (1950) interaction matrix, for example, is a special use of the sociomatrix, which is also called "who-to-whom" matrix.*

The sociomatrix or "who-to-whom" matrix allows the presentation of full information on a given item of sociometric choice. It spreads all the data before the researcher for his scrutiny. Unlike the sociogram, or the digraph, it is appropriate for groups of any size. It does enable one to single out subgroups and isolates, but it does not in itself reduce the labor of analysis; if the matrix involves a large number of elements, determining the group structure, communication paths, etc., is still a lengthy and tedious task.

A more sophisticated variation of Forsyth and Katz's (1946 and 1960) procedure was proposed by Beum and Brundage (1950). It consists of first assigning weights to the rows of the matrix (from one to N beginning with the bottom row), then the average product of the elements in each column and the corresponding weight is maximized for each column, while the sum of the squares of the elements about the principal

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*Bales and his colleagues at the Harvard Laboratory of Social Relations have developed a method of "interaction process analysis" for observing, analyzing, and comparing behavior in small groups—especially groups devoted to decision-making or problem-solving. Bales uses a "who-to-whom" matrix to study, for example, acts as indicants of the relationships among the group members. The Bales matrix allows also such relationships as which members of the group talk to which other member.

diagonal is minimized. The matrix is then rearranged so that the column with the highest average (rank one) is moved to the extreme left and the corresponding row is moved to the extreme top. The next-ranking column is placed next and the corresponding row is placed in position two from the top, and so on.

One advantage of this improved technique suggested by Beum and Brundage (1950) is that the numerical values of the cell entries are not limited. They may be choices, ratings, rankings, percentages, or any other measures of interpersonal relations. In addition, the final solution can be used for further types of analysis, such as the factor analytic procedure suggested by McRae (1960). More important, it can be adapted for computer operation, as shown by Borgatta and Stoltz (1963).

Digraphs and Matrices

The present section centers on some of the relationships between digraphs and matrices, and a few concepts that are basic for an understanding of these relationships. They will perhaps be better explained by illustration.* Consider a digraph (D) of five points, $V = \{a, b, c, d, e\}$ whose relations consist of ordered pairs (ac), (ae), (da), (dc), (de), (ea). Figure 5 shows this digraph with its adjacency matrix.**

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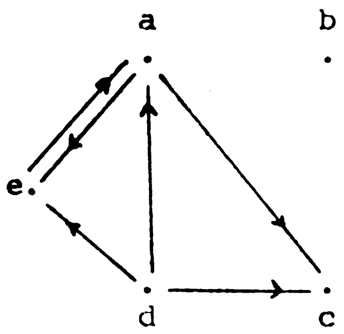
*The terminology as well as the mathematical notations in this area seem to vary from author to author. The terms used here, and their definition follow most closely Harary and others (1965) and Luce and Perry (1966).

**Given a digraph D, its adjacency matrix, $A(D) = [a_{ij}]$, is a square matrix with one row and one column for each point of D, in which the entry $a_{ij} = 1$ if line a a is in D, while $a_{ij} = 0$ if $a_i a_j$ is not in D. A digraph may have more than one adjacency matrix, depending on the ordering of the points of D. Thus, if we altered the ordering of the

D:


A (D):

	a	b	c	d	e	Row Sum
a	0	0	1	0	1	2
b	0	0	0	0	0	0
c	0	0	0	0	0	0
d	1	0	1	0	1	3
e	1	0	0	0	0	1
Column Sum	2	0	2	0	2	

Figure 5. Example of a digraph (D) with its adjacency matrix A(D).

Certain features of a digraph may be readily seen in its adjacency matrix. An example is the symmetry or asymmetry of a relation (or of the digraph itself).* If a relation is asymmetric, the existence of the line $a_i a_j$ precludes the existence of a line $a_j a_i$. Thus if $a_{ij} = 1$ then $a_{ji} = 0$. Symmetric relations, on the other hand, are those of mutual choices or two-way communication, for example, the relations (ae), (ea) in digraph D and in its adjacency matrix in Figure 5.

Another important feature in the adjacency matrix is its row and column sums, which indicate the number of lines originating and terminating at each point of the digraph. If we take digraph D in Figure 5 and its adjacency matrix to represent a communication network,

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points of the digraph shown in Figure 5, we might obtain a different adjacency matrix (although the digraph might remain the same). We will refer to the adjacency matrix of a digraph assuming that the order of the points is understood. For detail discussion, see Harary and others (1965).

*Luce and Perry (1966) use the term antimetry in the same sense of asymmetry as used here (i.e., lack of mutual choice in a relation).

each of its points (which could represent persons) can be classified as follows:*

<u>Transmitter</u> - A point whose outdegree is positive and whose indegree is 0. In a communication network a transmitter corresponds to a person who can send but not receive messages. In digraph D, the individual represented by point d is an example.

<u>Receiver</u> - A point whose outdegree is 0, and whose indegree is positive. A receiver corresponds to a person who can receive but not send messages. In digraph D, c is an illustration.

<u>Carrier</u> - A point whose outdegree and indegree are both 1. Corresponds to a person who can both send and receive messages. In diagraph D, e is an example.

<u>Isolate</u> - A point whose outdegree and indegree are both 0. An isolate person in a communication network can neither send nor receive messages. In digraph D, b is an example.

Any other point not included in this classification is called an <u>ordinary point</u>. As a rule, a person in such a position can both send and receive messages, as for instance, the individual represented by point a, in digraph D, Figure 5.

One may see at once that Harary and others' classification is very similar to that mentioned in the last part of Chapter I. There we referred, for example, to communication leaders, liaisons, and isolates.

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*This classification scheme is borrowed from Harary and others (1965), and is used here for illustrative purposes. Obviously, other typologies may be used in the same context. The term outdegree of a point a, written od(a), is the number of lines from a. The od(a) of a point a, written id(a), is the number of lines to a. The id(a) of the corresponding point is given by the column sum of the adjacency matrix.

A communication leader could be a person represented by an ordinary point, in Harary and others' classification. A liaison could be a carrier, and an isolate is similarly defined in both schemes.

Summary

The purpose of the present chapter was to briefly examine approaches to relational analysis. As we saw in the course of our discussion, each of the three approaches reviewed here (i.e., the sociogram, the digraph, and the sociomatrix) has its advantages and limitations. One advantage of both the sociogram and the digraph is that they offer a pictorial view of the patterns of interconnections of the system under consideration. On the other hand, they are both difficult to comprehend when dealing with a relatively large N, or sample size, or when the types of relations studied are complex in nature (i.e., when several alternative sociometric choices are allowed). The digraph has certain obvious advantages over the sociogram, in that the former is usually constructed on the basis of mathematically-derived rules, while the latter is usually built unsystematically.*

The sociomatrix does not have the pictorial effect of sociograms or digraphs, but it also spreads the data before the researcher for his scrutiny. Furthermore, it is appropriate for groups of any size. What is more important, however, is the fact that different algebraic manipulations are feasible with sociomatrices. The next chapter focuses on one such type of algebraic manipulation, that is, matrix multiplication.

*Spilerman (1966) developed a computerized method that allows the construction of digraphs (of symmetrical relations only) directly from sociomatrix data.

CHAPTER III

MATRIX MULTIPLICATION IN THE ANALYSIS OF INTERPERSONAL COMMUNICATION

A significant step forward was taken when Festinger (1949) and Luce and Perry (1949) outlined the application of matrix multiplication for the sociomatrix. This procedure allows identification of more formally defined structures, as well as the analysis of indirect relations. Essentially what they propose is the manipulation of matrices by means of raising them to n-powers in order to determine n-chains among group members, as well as the tendency toward subgroup or clique formation. If A is a square matrix, its power can be formed:

$$A^2 = AA,\ A^3 = A^2A,\ \text{etc., and, } A^{\circ} = 1$$

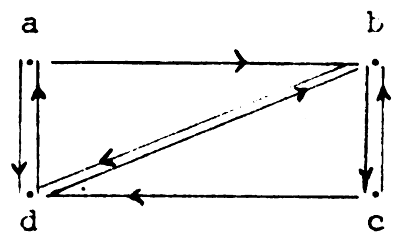
The entry of A^2 is:*

$$A_{ij}^{(2)} = a_{i1}a_{1j} + a_{i2}a_{2j} + \cdots + a_{in}a_{nj}$$

As an illustration, consider a simple digraph D of four points. $V = \left\{\underline{a}, \underline{b}, \underline{c}, \underline{d}\right\}$ whose relations are ($\underline{ab}$), ($\underline{ad}$), $\cdots$, ($\underline{da}$). Such a digraph, and its adjacency matrix together with its squared

*This means: the number which goes into the cell corresponding to row $\underline{i}$ and column $\underline{j}$ of the squared matrix is obtained by multiplying each row $\underline{i}$ of the original matrix by the corresponding cell in column $\underline{j}$, and then adding up the product. The product will be different from zero only if a unit appears both in the $\underline{i}$ row and in the $\underline{j}$ cell being considered. For discussions on matrix operations, see, for example, Kemeny and others (1966), Host (1963), or McMinn (1962).

matrix, A^2, are shown in Figure 6.



A:

	a	b	c	d
a	0	1	0	1
b	0	0	1	1
c	0	1	0	1
d	1	1	0	0

A^2:

	a	b	c	d
a	1	1	1	1
b	1	2	0	1
c	1	1	1	1
d	0	1	1	2

Figure 6. Example of a digraph with its adjacency and squared matrices.

Let us suppose that digraph D and its adjacency matrix A in Figure 6 represent the choice patterns in a hypothetical four-member group. Reading across row 1 in matrix A we find that person a chooses persons b and d. Column 1 shows that person a is chosen by person d. By inspection, we can therefore perceive in matrix A direct, one-step connections among the group members.

The squared matrix A^2 shows, however, indirect, two-step connections among the group members. For example, in the squared matrix A^2 we see that cell ac has a value of 1 (in the original matrix, A, this cell has a value of 0). This means that a chose another person who chose c. In fact, the following relationship can be seen in digraph D: $a \longrightarrow b \longrightarrow c$. In cell ca of matrix A^2 we also find a value of 1, indicating the relationship: $c \longrightarrow d \longrightarrow a$.

Unlike matrix A, the squared matrix A^2 has values other than 0's and 1's. The values higher than one in matrix A^2 indicate the number of two-chains by which two persons are connected. For example, if cell _ac_ has a value of 2, we may conclude that _a_ chose two persons who chose _c_. But since cell _ac_ has a value of 1, we know that _a_ chose one person who chose _c_. This can be seen in digraph D.

Matrix A has 0's in its major diagonal (there were no self-choices). Matrix A^2, however, has 1's and 2's. These represent the number of mutual choices received by the group members. Cells _bb_ and _dd_ both have two mutual choices, while cells _aa_ and _cc_ have one each.

We can see, then, that the rows and columns of the squared matrix A^2 show how well connected to the group an individual is. As Festinger and others (1950, pp. 140-142) point out, the meaning of these indirect connections between group members is quite important, be it indicative of influence, channels of communication, or any other type of interpersonal connection. For example, if the original sociometric choices are designed to measure patterns of influence within a social system such as a community, matrix A would indicate that person _x_ exerts direct influence upon person _y_. The squared matrix, A^2, would however indicate the extent of indirect influence which person _x_ has within the system, since it shows which other persons he influences indirectly, that is, through _y_, _z_, etc.

If the original sociometric choices are designed to trace channels of communication, the squared matrix, A^2, would show that a given item of information originating with person _x_ (i.e., a transmitter), would reach persons _v_, _w_, and _z_ in two steps. If any of these three persons is a carrier (a person who can both send and receive messages), the item of information may also be received (in three-steps) by persons q, u, etc. On the other hand, if individual v is a receiver (he can receive but not send messages), the item of information that reaches him would not be passed on to other community members.

By adding the original and the squared (or n^{th}) matrices, the researcher may know, for example, how many elements in the communication system receive any particular item of information if this message is started with person x. He may also obtain answers to such questions as: "Who influences whom" in a specified number of steps? Which elements are influenced by only a few other elements, and which are influenced by a large number of them? Who are the persons in the system most indirectly connected to each other? What proportion of all possible connections actually exist? Who are the communication leaders, liaisons, isolates, and so forth?

Knowledge of the indirect connections within a group may also provide the criteria for classifying people according to their position along n-chains (i.e., one-step, two-steps, etc.) in regard to a given information input. The n^{th} matrix can be partitioned into subgroups (or submatrices) representing persons who exhibit similar characteristics along the n-chains dimension. Lin (1968) combined awareness data with sociometric data for three Michigan high schools,* by

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*Awareness refers to time of initial knowledge of an innovation. Sociometric data were based on nominations of three individuals whose opinions respondents frequently sought. Lin's intent was to determine whether differences found in the variability of awareness dates in three schools were due to differences in communication patterns.

ordering the respondents in the matrix (A) so that the earliest knower occupied the first row and column in the matrix, while the latest knower occupied the last row and column. The matrix was partitioned into groups of respondents who became aware of the innovation during the same month. Three types of submatrices originated from this, each representing one type of communication pattern:

1. Upward communication, representing a respondent's nomination of another member of the system who had become aware of the innovation earlier than himself.

2. Downward communication, representing a respondent's nomination of another person who had become aware of the innovation later than himself.

3. Horizontal communication, representing diagonal cells.

Clearly, similar procedures may be applied to other social systems, such as a community.

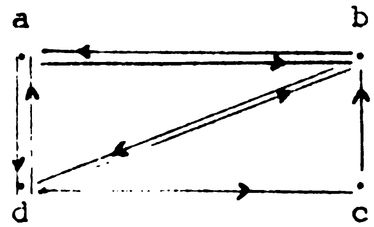
Clique Identification

Festinger (1949) and Luce and Perry (1949 and 1966) give special attention to the problem of clique identification. What they recommend is to extract a symmetric submatrix S from the original matrix A. The entries of the matrix S will be determined by $s_{ij} = 1$ if $a_{ij} = 1$, and otherwise $s_{ij} = s_{ji} = 0$. To illustrate this procedure, digraph D with its adjacency matrix A (the reciprocated choices are in parenthesis), and the submatrix S, are presented in Figure 7.

If a matrix is symmetrical about the main diagonal, the corresponding rows and columns are identical. As can be seen in matrix S,

Figure 7, row one is the same as column one, row two is the same as

D:



A:

	a	b	c	d
a	0	(1)	0	(1)
b	(1)	0	0	(1)
c	0	1	0	0
d	(1)	(1)	1	0

S:

	a	b	c	d
a	0	1	0	1
b	1	0	0	1
c	0	0	0	0
d	1	1	0	0

Figure 7. Example of a digraph with adjacency and symmetrical matrices.

column two, etc. When a symmetrical matrix is raised to the n^{th} power, the product is also symmetric. This is shown in Figure 8, which represents the 2nd and 3rd powers of matrix S.

S^2:

	a	b	c	d
a	2	1	0	1
b	1	2	0	1
c	0	0	0	0
d	1	1	0	2

S^3:

	a	b	c	d
a	2	3	0	3
b	3	2	0	3
c	0	0	0	0
d	3	3	0	2

Figure 8. Example of a squared and cubed symmetric matrix.

The matrix S^3 has a similar meaning to that of the squared matrix S , with the difference that it shows the three-step links between individuals in the group. For this reason, it provides criteria for clique identification. As previously defined, a clique consists of a subsystem of three or more elements each in mutual interaction with each other element. The major diagonal of matrix S^3 indicates which individuals in the group are clique members and which are not. If an individual's cell in the main diagonal shows a value other than zero, he is a member of a clique. Otherwise he is not. In our example, only c is not a clique member, a fact that can be readily seen by examining digraph D in Figure 7.

Besides identifying clique members, the values in the main diagonal also indicate the number of individuals in the clique. From matrix S^3 one can see, for example, that person a has a 2 in his main diagonal cell. This value of 2 means that a can reach himself by two different three-step connections, that is, $a \rightarrow b \rightarrow d \rightarrow a$, or $a \rightarrow d \rightarrow b \rightarrow a$. We can see, therefore, that a is a participant in a three-member clique, the other two members being b and d.

When dealing with large groups, where more than one clique may exist and these cliques may be composed of different individuals, the number appearing in the main diagonal of the S^3 for each person will be equal to (n-1) (n-2) (Festinger and others, 1950, p. 144). A person in a clique of three members would have a diagonal cell value of (3-1) (3-2) = 2, which is in fact the value appearing on the diagonal cells of a, b, and d on matrix S^3, Figure 8. A person in a clique of four members would have a diagonal cell value of (4-1)(4-2) = 6, and so on.

Once we have established which individuals in a group are clique members and which are not, as indicated by their cell values in the main diagonal, it may also be desirable to identify the other clique members. This may be done as follows: their cell values in the S^3 matrix row will have a minimum value of $(n-)(n-2) + 1$ (Chabot, 1950, p. 139). For a clique of three members, as in our example (matrix S^3, Figure 8), this value will be 3. If we take b, for instance, we can see that a and d are the other members of the clique, since they have a value of 3 along b's row.

Several investigations subsequent to the original formulations of the matrix multiplication technique by Festinger (1949) and Luce and Perry (1949) were directed toward analyzing ever more complex types of relationships, as well as toward solving some of the problems involved in the use of this system (e.g., Katz, 1953; Harary and Ross, 1957; Hubbell, 1965; Cartwright and Gleason, 1966; Sabidussi, 1966; Spilerman, 1966).

One problem with the matrix multiplication approach relates to situations in which an individual is a member of more than one clique. Under these circumstances, the use of a matrix like S^3 does not seem to be of much help. One alternative is, of course, to refer back to the original matrix, A, where the connections may be individually traced. Another alternative proposed by Luce,* consists of computing the matrix powers, $A, A^2, \ldots, A^n$, and then adding up the product $(A + A^2 + \ldots + A^n)$ to form a matrix $B(n)$. Next, a pseudo-structure $B'(n)$ is formed, with 0's where $B(n)$ has zeros, and 1's where $B(n)$ has positive entries. The symmetric part of $B'(n)$ is then extracted and the cliques are

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*Cited by Chabot (1950, p. 139), from an unpublished paper by Duncan R. Luce.

computed as if it were an ordinary sociometric matrix. According to Luce, the cliques of B'(n) are identical with the n-cliques of A. The method seems, however, a bit complicated and laborious.

Harary and Ross (1957) extend Festinger's (1949) and Luce and Perry's (1949) approach to the determination of the cliques in a group having three or fewer cliques. They begin by identifying a "unicliqual" person (i.e., a person who belongs to exactly one of the cliques in a group), then by an induction-reduction method, they proceed to identify the cliques in the group.

Working with the transpose of a matrix identical to that used by Festinger and Luce and Perry,* and drawing on Katz' work (1953), Hubbell (1965) discusses a method for clique identification based on a generalization of Leontif's input-output model. Hubbell's discussion centers on the notion that if person a chooses person b as a friend, then there is a likelihood that b will be able to influence a. Hubbell's approach departs from previous work in the sense that it allows weighted links between 0 and 1 in the N by N matrix. The weights can be positive, negative, or neutral. As with other procedures, cliques are identified on the basis of clusters of individuals with symmetrical relations. One additional feature of this technique is that all powers of the matrix can be used, thus eliminating the arbitrary choice of S^3 set up in earlier attempts (e.g., Festinger (1949) and Luce and Perry (1949).

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*The transpose of a matrix, A, written A^t, is the matrix obtained by writing the rows of A, in order, as columns. In Hubbell's terms, a_{ij} denotes, therefore, j's choice of i, rather than i's choice of j.

Hubbell illustrates his presentation with data from McRae (1960), and then compares his resulting cliques with those identified by McRae, concluding that the input-output model has greater discriminating power than McRae's factor analytical technique.

Identification of n-Chains

Another problem that arises in communication research has to do with the precise identification of what Luce and Perry (1966) define as n-chains, i.e., links of n-steps in length from *i* to *j*. Cartwright and Gleason (1966) discuss this same problem within the framework of graph theory, and prefer to use the terms paths and cycles. The problem, however the contexts of its discussion, is to find the number of ways one can go from one point to another using a given number of lines, without passing through any point more than once. One may want to know, for instance, how many ways a message can go from person *a* to person *z* through a network in exactly n-steps while satisfying the requirement that no person hear the message more than once.

The method of matrix multiplication, as suggested by Festinger (1949) and Luce and Perry (1949 and 1966), allows what Coleman (1964, p. 447) calls "doubling back," that is, the same links are counted more than once. For example, a three-person chain from *a* to *b* in digraph D (Figure 9), using matrix multiplication, will result in the connections: $a \longrightarrow d \longrightarrow a \longrightarrow b$.

In an attempt to solve this problem of redundant sequences, Coleman (1964, pp. 447-448) devised a method which consists of

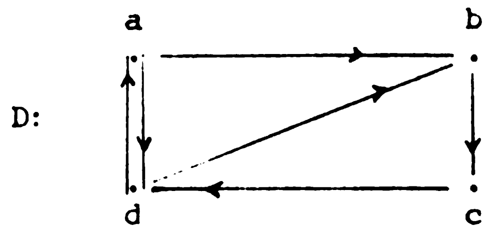


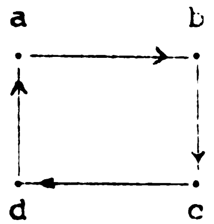
Figure 9. A digraph illustrating the problem of redundant sequences.

separating each row vector rather than using the entire matrix, so that each person's connections are calculated separately. But as Coleman himself acknowledges, this alternative is only an approximation of what would be desirable. While the older method of matrix multiplication is marred because it allows redundant sequences, Coleman's alternative procedure counts too few. For example, in digraph D, Figure 9, the chain a ⟶ d ⟶ b ⟶ c would not be counted when Coleman's procedure is used, because that chain includes the connection b ⟶ c, already part of the chain a ⟶ b ⟶ c.

Ross and Harary (1952), and Parthasarathy (1964), offer alternative solutions to the problem of redundant sequences, but their formulas are quite formidable and there seems to be little likelihood that a general solution is practical by their method.

The Distance Matrix

Both the problem of multiclique membership and that of the determination of n-chains seem to be satisfactorily overcome by the use of a distance matrix.* Harary and others (1965, pp. 134-138) define the distance matrix of a digraph as "the square matrix of order 'p' whose entries are the distances d_{ij}" [d_{ij} being the distance $d(a_j a_i)$ from a_j to a_i]. If there is no path from a_i to a_j, then $d_{ij} = \infty$. The distances in a digraph such as the one in Figure 10 are not difficult to figure, and are shown in the distance matrix D(I):

D: 

D(I):

	a	b	c	d
a	0	1	2	3
b	3	0	1	2
c	2	3	0	1
d	1	2	3	0

Figure 10. Example of a digraph with its distance matrix.

Matrix D(I) presents two main features: (1) its major diagonal has only 0 entries, because the distance from every point to itself in digraph D is 0, and conversely; and (2) every one of its entries is finite. On the other hand, three of the entries of a point a in matrix D(I), associated with digraph D, Figure 11, are ∞, because a is a transmitter and, therefore, cannot be reached from any other point.

A distance matrix D(I) is constructed from an adjacency matrix A as follows: (1) enter 0's on the main diagonal of D(I), so that $d_{ii} = 0$, (2) enter 1 in the D(I) wherever $a_{ij} = 1$, so that $d_{ij} = 1$.

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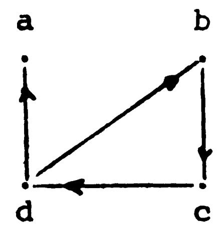
*Cartwright and Gleason (1966) present a method for finding both the number of paths and cycles of any given length through a series of operations with the distance matrix to analyze sociometric data for three school systems in the State of Michigan.

For n-powers of A, enter <u>n</u> wherever $a_{ij}^{(n)} = 1$, and as long as there is no prior ij entry in the D(I), so that $d_{ij} = n$. In case any cells remain

D:



D(I):

	a	b	c	d
a	0	2	3	1
b	∞	0	1	2
c	∞	2	0	1
d	∞	1	2	0

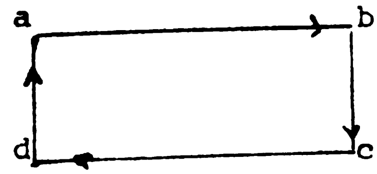
Figure 11. Example of a digraph with its distance matrix.

open on D(I) after the A^{n-1} power has been computed, enter ∞ in all (Harary and others, 1965, p. 135). These procedures are illustrated in Figure 12.

If matrix A in Figure 12, were raised to the fourth power (A^n), all four cells on its main diagonal would be 1, consequently, all entries on the main diagonal of matrix D(I) would be 4. However, we know beforehand that $d_{ii} = 0$. Thus, unless one is particularly interested in analyzing the lines that have the same first and second points (<u>loops</u>), there is no need to go beyond the A^{n-1} power. In actual computation, it may be more practical to substitute ∞ for zeros, but this does not seem to be of major relevance.

In addition to showing the communication patterns of one, two . . . or n-1 steps or chains, the distance matrix permits the computation of the communication domain of each group member, on the basis of which subgroups, cliques, dyads, liaisons, and isolates can be identified.

D:



$$A = \begin{array}{c} \\ a \\ b \\ c \\ d \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \end{bmatrix} \end{array} \qquad D(I) = \begin{array}{c} \\ a \\ b \\ c \\ d \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} 0 & 1 & \infty & \infty \\ \infty & 0 & 1 & \infty \\ \infty & \infty & 0 & 1 \\ 1 & \infty & \infty & 0 \end{bmatrix} \end{array}$$

$$A^2 = \begin{array}{c} \\ a \\ b \\ c \\ d \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \end{array} \qquad D(I) = \begin{array}{c} \\ a \\ b \\ c \\ d \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} 0 & 1 & 2 & \infty \\ \infty & 0 & 1 & 2 \\ 2 & \infty & 0 & 1 \\ 1 & 2 & \infty & 0 \end{bmatrix} \end{array}$$

$$A^3 = \begin{array}{c} \\ a \\ b \\ c \\ d \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \end{array} \qquad D(I) = \begin{array}{c} \\ a \\ b \\ c \\ d \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} 0 & 1 & 2 & 3 \\ 3 & 0 & 1 & 2 \\ 2 & 3 & 0 & 1 \\ 1 & 2 & 3 & 0 \end{bmatrix} \end{array}$$

Figure 12. Illustration of computation procedures for a distance matrix for A, A^2, A^3.

A person's communication domain is the number of system members directly or indirectly connected to him. Cliques and subgroups are identified by simply selecting the persons with the highest communication domain and then tracing those who are directly or indirectly connected to them. Once cliques and subgroups are identified, dyads, liaisons, communication leaders, and isolates, can also be found.

The distance matrix provides also a basis for the computation of a centrality index and a prestige index for each element in the system. The centrality index is the sum of all chains in the influence domain divided by the influence domain. The prestige of each element is the influence domain divided by the product of his centrality index and the number of other elements (N-1).

Computation of these indices has been programmed for computer use, and are described in more detail in the next chapter.*

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*These indices may be computed through a program written by Dr. Nan Lin, of The Johns Hopkins University.

CHAPTER IV

COMMUNICATION INTEGRATION IN TWO BRAZILIAN COMMUNITIES

The two preceding chapters deal with the use of different techniques for the analysis of relational data. As shown in Chapter III, the matrix multiplication approach is suitable for the formation of indices and process variables, which in turn allow, when dealing with relational data, a shift in the focus of analysis: from individual to dyads, cliques, subgroups, or larger systems. The purpose of the present chapter is to demonstrate how the matrix multiplication approach can be used to arrive at indicators of one specific process variable, namely, communication integration. For illustrative purposes, data are drawn from two Brazilian communities.

The Selection of the Two Communities

The data used in the present study were obtained in two agricultural communities selected from a sample of 20 communities in the state of Minas Gerais, Brazil. This sample derives from an original selection of 80 communities initially included in Phase I of the Project "Diffusion of Innovations in Rural Societies."*

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*See Rogers (1964) for a description of the Project "Diffusion of Innovations in Rural Societies."

In brief, these 80 communities were selected from a proportional stratified sample of 40 *municipios* (counties) in which the Agricultural Extension Agency of the State of Minas Gerais (ACAR) had local offices. The local ACAR agents in each of these 40 *municipios* were then requested to designate the two communities within their respective *municipios* in which they had *most* and *least* success in their programs. This procedure resulted in a selection of 80 communities, 40 "more successful" and 40 "less successful."*

A discussion of the criteria that dictated the selection of the 20 communities included in Phase II of the Brazil study is found in Herzog and others (1968). In essence, they had to be suitable sites for experiments to be carried out in Phase III of the Brazil study. Since these experiments involved mainly literacy training and radio farm forums, the communities had to be within reach of a single broadcast station, as well have some pre-determined place where the residents could meet to participate in one of the two experimental treatments carried out (literacy training or radio farm forum). Also, they had to be relatively easily assessible from Belo Horizonte, the Project Headquarters, in view of the anticipated need to travel to each community to carry out the Phase III treatments. Furthermore, half of the communities should be of "greater success" and half of "less success."

Lists of residents in each of these 20 communities were made in

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*More detailed description of the sampling procedure used in Phase I of the Brazil study may be found in Whiting and others (1967).

advance, so that virtually all persons who were major decision-makers, for their respective households, and who owned at least part of the land they worked, were interviewed.

The communities used in the present study are the two, out of the 20 indicated previously, with the highest and the lowest mean community innovativeness score.* The selection of these two communities was guided by two assumptions:

1. Provisionally, at least, we can assume that the community with the highest innovativeness score is relatively more "modern," while the one with the lowest innovativeness score is relatively more "traditional." These two terms--modern and traditional--are henceforth attached to each of the two communities.

2. The selection of a "modern" and a "traditional" community was based on the assumption that these two types of social systems exhibit considerable differences in their internal communication patterns, especially when a variable such as communication integration is concerned.

Definition of Communication Integration

As previously defined (Chapter I), a communication system, which may be a subsystem of a social system (in our case, a community), embraces such communication subsystems as cliques, subgroups, chains, and dyads. Furthermore, a communication system contains such elements

*Innovativeness, defined in terms of earliness or lateness in adopting an innovation (Rogers, 1962), was measured as the normalized years of adoption of up to 12 innovations, especially selected for each of the 20 communities.

as communication leaders, liaisons, and isolates.

The degree of integration of a communication system can be viewed from at least two major perspectives: external and internal. External communication integration refers to the degree to which the channels available to the system members are interconnected via exposure to these channels.* Internal communication integration is defined as the degree to which the elements and the subsystems of a communication system are interconnected via interpersonal channels.

The internal and external aspects of a communication system seem to be closely interrelated. Using the two-step flow hypothesis (Lazarsfeld and others, 1948) as an analogy, we may assume, for example, that a communication system which exhibits a relatively high degree of internal communication integration is also likely to be characterized by a relatively high degree of external communication integration. Conversely, a system with a relatively low degree of internal communication integration may also show a relatively low degree of external communication integration. Our major concern in the present study is, however, with internal communication integration, which we refer generally to communication integration, to facilitate discussion.**

Within our framework, the degree of integration of a

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*Coughenour (1964) uses the term "integration of communication structure" to refer essentially to what we are calling "external communication integration."

**Yadav's (1967) study of two villages in India is the only available empirical investigation in which "internal communication integration," as here defined, is examined.

communication system involves at least two levels of analysis: (1) the patterns of interconnections exhibited by each system element, in reference to each other and to each communication subsystem; and (2) the patterns of interconnections shown by the subsystems. Thus, we are basically interested in determining the communication links among individual members of the system, as well as the relationships among communication systems.

Operationalization of Communication Integration

The patterns of interconnections among individual members and among subsystems of a communication system may be analyzed on the basis of relational data, gathered through sociometric-type questions. One specific type of relationship dealt with in Phase II of the Brazil study is based on responses to the following question:

> "Who are your three best friends with whom you talk the most?"

Operationally, therefore, communication integration is indicated by the sociometric choices received by the system members on a criterion explicitly concerned with interpersonal communication among informal friends.*

The data thus obtained were fed into a computer program (called

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*Following Parsons (1959), we may view interpersonal communication as instrumental or consumatory. Instrumental communication refers to those interpersonal relations initiated for the purpose of seeking certain specific information, such as the advantages or disadvantages of innovation. Consumatory communication refer to those interpersonal relations initiated and maintained for the purpose of friendship.

Clique 1B) to reproduce a two-valued (1-0) N by N matrix, with each row representing a nominating person, and each column designating a nominee.*

The 1-0 matrix was fed into another computer program, called ICPC, whose main features include:**

1. A distance matrix, which has in each of its cells either (1) a positive integer indicating the number of chains in the shortest communication link between element i and j, or (2) a 0 if such communication link between i and j does not occur. When raised to n-powers, the distance matrix will show in its cells values of:

(a) 0 - meaning that no communication links occur between i and j;

(b) 1 - indicating one-step connections between i and j, or

(c) 2, 3 . . . n - showing 2, 3 . . . n-step connections between i and j.

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*The Clique 1B program prints out an N by N matrix with 1-0 values, the row and column sums, and a list of nominators-nominees. It performs multiplication of the N by N matrix up to the 7th power. Yet its routine does not take care of redundant relationships, with the result that the products appearing in each cell of the matrix do not represent the actual communication links at a given step (two, three, etc.).

**As previously indicated, the ICPC program was written by Dr. Nan Lin, of The Johns Hopkins University. Its main characteristics are discussed in Lin (1968). Briefly, the present capacity of the ICPC version adapted for use at Michigan State University Computer Center is 80 elements. The 1-0 distance matrix can be raised to a maximum of 50 powers. For the present study the two 1-0 matrices, corresponding to the modern and traditional communities, were first raised to the 10th power, but since very few elements qualified, in a second run they were raised to the 4th power. This second output provides the basic information discussed in the present chapter.

2. The communication domain of each element in the distance matrix, defined as the number of individuals directly or indirectly linked to i.

3. A centrality index of each element, defined as the sum of all chains in the communication domain divided by the communication domain.

4. A prestige index of each element, defined as the communication domain divided by the product of the centrality index and the number of other elements (N-1).

Indicators of Communication Integration

Despite the relatively large amount of information provided in its output, especially in terms of mechanical computations, the ICPC program is still limited insofar as certain features are concerned. Apparently, this program was initially designed for research in which individuals are the unit of analysis. Thus, the determination of indicators for a variable such as communication integration requires additional computational operations. Fortunately, however, most of the information needed for the computation of possible indicators of communication integration can be extracted from the ICPC program output. A summary of these possible indicators, both for the "modern" and the "traditional" communities, is provided in Table 1.

By first selecting the individuals with the highest communication domain, in each of the two communities, and then tracing his direct and indirect connections we were able to determine the following indicants of communication integration: number of isolates (those who neither chose nor were chosen by any one); number of persons who received no choice, but chose at least another person; number of liaison individuals (those who interlink two or more subgroups); dyads (two persons with mutual choices); and subgroups (two or more individuals linked mainly--but not necessarily exclusively--through unreciprocated relations).

Communication leaders were determined by selecting those individuals who obtained at least ten percent of the maximum possible

Table 1. Possible Indicators of Communication Integration in a Modern and in a Traditional Community in Minas Gerais, Brazil.

Indicators	Modern Community (N = 60)		Traditional Community (N = 77)	
	Number	Percent	Number	Percent
1. Isolates	1	1.7	12	15.6
2. Received No Choices	26	23.3	54	70.1
3. Communication Leaders	13	21.6	8	10.3
4. Liaison Individuals	4	6.6	3	4.0
5. Reached in Two-Step Connections	59	98.3	29	37.7
6. Dyads	12	--	1	--
7. Subgroups	4	--	3	--
8. Cliques	0	--	0	--
9. Mean Number of Choices Received by Individuals in the Community	1.3	--	0.7	--
10. Mean Communication Domain Received by Individuals in the Community	3.6	--	1.4	--
11. Mean Centrality Index Received by Individuals in the Community	0.9	--	0.4	--

communication domain (N-1).

The number of individuals reached in two-step connections was determined by counting in each of the two distance matrices (raised to the fourth power) those cells which showed a two in them.

The other three indicants (mean number of choices, mean communication domain, and mean centrality index) were determined (respectively) by dividing the sum of all the scores or measures by N-1 (since self-nominations were not considered in the present study).

Conclusions

The indicants shown in Table 1 are rather unrefined measures of communication integration. Nevertheless, they serve to show that marked differences do exist between the modern and the traditional communities in terms of their communication patterns. By examining the values for each of the 11 indicants shown in Table 1 we can infer that the modern community exhibits relatively more integration in its communication system than does the traditional community.

The foregoing conclusion lends support to two assumptions stated in an earlier section of the present chapter. We assumed that the community with the highest innovativeness score is relatively more modern, while the community with the lowest innovativeness score is relatively more traditional. We further assumed that a "modern" and a "traditional" community exhibit considerable differences in their internal communication patterns, especially when a variable such as communication integration is considered.

When defining internal and external communication integration we proposed that these two concepts are interrelated. Table 2 shows four indices of mass media exposure for each of the two communities.*

Table 2. Mass Media Exposure in a Modern and in a Traditional Community of Minas Gerais, Brazil.

Medium	Modern Community (N = 60)	Traditional Community (N = 77)
1. Newspaper Readership	.35	.06
2. Radio Exposure	.75	.34
3. Television Exposure	.78	.21
4. Movie Attendance	.17	.05

By inspection of the values in Table 2 we may conclude that the modern community shows relatively higher indices of exposure to mass media than the traditional community. If we accept these indices as one type of indicants of external communication integration, at least on a provisional basis, we may conclude that the modern community is relatively more integrated than the traditional community in terms of its external communication system.

As a general conclusion we may say, therefore, that innovativeness, external communication integration, and internal communication

*These indices were derived as follows: (1) newspaper readership, the percent who regularly read a newspaper; radio exposure, the percent who listen to one hour per day; television exposure, the percent who watch television; movie exposure, the percent who ever see movies.

integration are positively interrelated, as shown in Figure 13.

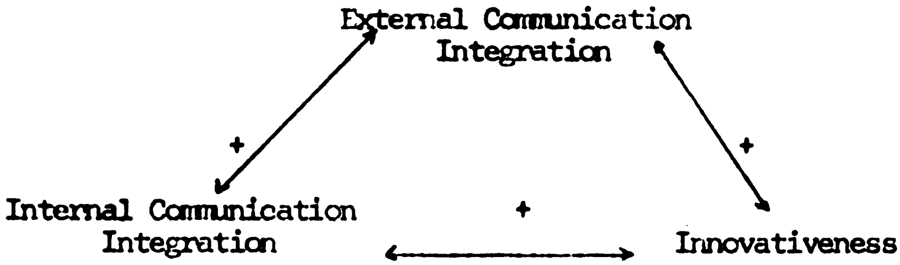

Figure 13. Possible relationships among external communication integration, internal communication integration, and innovativeness.

This general conclusion is by no means definite. It is possible, for example, that internal communication integration mediates external communication integration and innovativeness. In that case we would have a situation analogous to that found in Lazarsfeld and others (1948), i.e., a two-step flow of communication. On the other hand, it is also possible that internal communication integration is in itself a primary factor in the innovativeness process. Both of these questions can be answered only through additional investigations, in which more refined measurements and statistical procedures (such as partial correlation) could be employed.

CHAPTER V

SUMMARY, CONCLUSIONS, AND SUGGESTIONS FOR FUTURE RESEARCH

Summary and Conclusions

A major argument of the present thesis is that communication research has overemphasized individual behavior, and neglected communication interaction processes. One alternative to focusing on individuals as separate units, is to change to networks of relations among individuals as units of analysis. Under the latter perspective, the individual is treated as part of a larger system, rather than as an isolated or independent unit.

Pleas in favor of relational studies have received conspicuously little attention. One explanation for this neglect lies in the data-gathering techniques of past survey research. Recently, however, various techniques of measurement, data gathering, and data analysis have been utilized to provide focus on relationships rather than on individuals. Sociometric-type questions, as a technique of measurement, allows the identification of networks of communication surrounding each respondent. Two major data-gathering techniques are appropriate for relational studies: (1) the "snowballing" technique, and (2) the "saturation" sample.

The analysis of relational data has two interdependent aspects: (1) the unit of analysis, and (2) the techniques of analysis. The unit of analysis may be any of the following systems: a dyad, a chain, a clique, a subgroup, or a communication system as a whole. A communication system may be part of a larger system (i.e., a community). As such, it embraces subsystems as dyads, chains, cliques, and subgroups. In addition it contains such elements as communication leaders, liaisons, and isolates.

The analysis of relational data, with focus on any of the subsystems indicated in the preceding paragraphs, may be performed with the use of (1) charts or diagrams, such as sociograms, digraphs, and sociomatrices, or (2) by means of matrix multiplication.

The major objective of the present study was to examine the relative merits of the matrix multiplication technique, as compared to the sociogram, the digraph, and the sociomatrix.

Another objective of the present study was to illustrate the use of the matrix multiplication approach with relational data from two Brazilian communities.

As regards the first objective, one major conclusion that can be drawn from the study is that the matrix multiplication technique has obvious advantages over merely diagrammatic presentations, and importantly, its use does not necessarily exclude the use of one or more of the other three techniques.

A major feature of the matrix multiplication technique is the fact that different investigators can manipulate the same data and the results yield will tend to be similar. Sociograms, or mere diagrammatic presentations, on the other hand, may provide different visual images, depending on the way they are constructed.

The interpretation of the results yielded by the matrix multiplication technique is relatively simple, whereas diagrams may become cumbersome and difficult to interpret, especially when a relatively large sample is involved.

An important characteristic of the matrix multiplication approach is objectivity in interpretation. The representational devices, frequently built on a trial basis, might not be as free from error. For example, two or three sociograms may look alike, or might even be identical, but it is often difficult to determine their actual differences or similarities. The matrix multiplication technique, on the other hand, permits the construction of indices, on the basis of which quantitative comparability becomes possible.

Still another feature of the matrix multiplication approach is its flexibility to deal with large samples. And perhaps more important, it has been programmed for computer use.

The application of the matrix multiplication technique to data obtained in a "modern" and a "traditional" community in Minas Gerais, Brazil, lends support to the foregoing conclusions. The method allows the identification of formal defined structures of the communication system, as well as the analysis of indirect relations. In addition, the formation of such indices as communication domain, n-step connections, etc., would be more difficult and less accurate if derived on the basis of merely diagrammatic techniques. It is clear, however, that for certain situations (i.e., visual effects), the combination of the matrix multiplication approach and diagrams is desirable.

Suggestions for Further Research

There are at least two broad (and interrelated) research emphases which deserve attention. One is methodological in nature, and the other conceptual. Under methodology we can distinguish two major domains: (1) additional applications of the matrix multiplication approach, and (2) the statistical measurement of indicators derived from the application of the matrix multiplication technique (as used in the present study).

Further Applications of the Matrix Multiplication Approach

The matrix multiplication technique applies to problems other than those discussed in the present study. Katz (1953) and, in modified form, Hubbell (1965), have used matrices to determine such indices as "sociometric status" or "cohesiveness." The procedure consists of multiplying each entry of the matrix by a coefficient, "a," representing the atenuation of influence or information at each step or chain of the structure. On this basis, several other results can be derived. For example, the n-power of the matrix can represent the amount of influence or information flowing, say, from i to j through exactly n-steps. The sum of the matrices to the 1, 2, . . . , n powers represents the total influence or information from i to j at n-steps or less. In addition, the sum of the infinite series may be either convergent or divergent for a given value of "a." If it is convergent, this means that the influence flow dies out; if divergent, it means that the influence increases as it circulates through the structure. It may be divergent in some portions of the structure, convergent in others.

Matrix multiplication has also been used for the analysis of two or more different structures, or for different relations. For example, if one has two groups, G_1 and G_2, then the structure $G_1 - G_2$ is a G by G matrix. Multiplying this by the G_2 by G_1 matrix will result in a matrix with a_{ij} entries. Other similar operations may be carried out; the interpretation of their results will, of course, rest on their underlying assumptions.

There are still other potential areas of application of the matrix multiplication approach. One of them applies, for instance, to the analysis of roles and status relations, within different types of social systems. The cell entry 1 could represent the existence of role-status relationships, and the cell entry 0 the absence of such a relationship.* As the areas of application of these techniques are extended, it is likely that they will prove increasingly valuable to social research.

Indicators Derived from the Matrix Multiplication Approach

As shown in Chapter IV, the matrix multiplication approach produces a series of indicators of a communication system. These indicators, as previously emphasized, are unrefined estimates of the patterns of interconnections exhibited by the system. Some of the indicators of communication integration dealt with in the present study are so interrelated that it is difficult to determine, at this point,

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*White (1963) studied kinship structures through a similar type of approach.

whether they are really independent estimates or just a slightly different aspect of one or more other characteristics. An important task for future research is therefore to further examine these indicators with the purpose of reducing them to valid and reliable indices.

One way of accomplishing the task referred to in the previous paragraph is through factor analysis. Another alternative is to construct ideal communication systems, with types ranging from a "completely integrated" system to one in which the patterns of communication are "entirely spread out." These two polar types of communication systems may then be treated by matrix multiplication, and the indicators derived from them can perhaps be used in determining indicators for communication integration of empirical systems, such as the two systems analyzed in Chapter IV.

Conceptual Problems

Another research realm that requires attention relates to conceptual and theoretical problems. A major variable that needs further theoretical (and methodological) consideration is communication integration. Communication integration was measured in the present study in terms of consummatory (merely social) interpersonal relations. The measurement should be expanded to include, for example, instrumental interpersonal contacts as well (i.e., those relations maintained to seek specific information, such as the adoption or rejection of innovations).

The idea that the diverse parts of a communication system normally cohere in some determinate fashion may prove useful in different contexts. It may help to explain, for example, how members of a social system accept, reject or modify innovations which are diffused from other systems. Administrators and change agents may be guided by the concept in their efforts toward introducing innovations into "less developed systems."

Communication integration has not been systematically studied as a major variable; but recent developments in modern society and in behavioral research point to the salience of the concept.* The paradigm presented in Figure 14 summarizes a series of provisional hypotheses that deserve further consideration. The position intended is merely to state possible antecedent and consequent conditions of internal communication integration. The anticipated relationships of the variables do not necessarily imply cause and effect.

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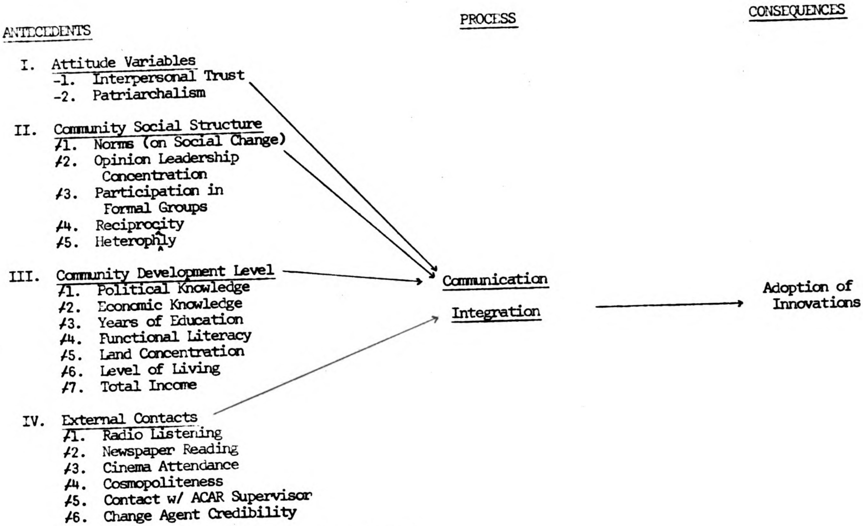
*Among those who have shown interest in communication integration are Wirth (1948), Shils (1962), and Deutsch (1953).



(+ or - = direction of hypothesized relationships)

Figure 14. Paradigm of variables and conceptual relationships with communication integration.

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