DOCUMENT RESUME

ED 137 880 CS 501 690

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TITLE The Validation of Mathematical Indices of Communication Structure.
PUB DATE 77
NOTE 35p.; Paper presented at the Annual Meeting of the International Communication Association (Berlin, May 29-June 4, 1977)

EDRS PRICE MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS *Communication (Thought Transfer); Group Structure; Information Theory; *Organizational Communication; Research; *Social Structure; *Sociometric Techniques; *Statistical Analysis; *Validity

ABSTRACT

Little research attention has been paid to the systematic validation of mathematical indices of social structure. The validation strategies in use remain largely implicit and generally fail to appreciate the multi-dimensionality of structure. The current paper proposes a new method designed to avoid these shortcomings and reports the results of its use in evaluating a set of 11 indices Potentially useful in measuring communication structure. Recommendations regarding the use of these indices for particular research purposes are made, along with suggestions for future research. (Author/AA)

The Validation of Mathematical Indices of Communication Structure[1]

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A paper to be presented at the International Congress on Communication Sciences, Berlin, Germany, May 1977; also to appear in <u>Communication yearbook 1</u>. New Brunswick, N. J.: Transaction, Inc., 1977.

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The Validation of Mathematical Indices of Communication Structure

The interdependence of theory and observation or measurement practices has often been noted (Woelfel, 1974). By influencing the way the world is perceived, observation or measurement practices obviously influence theory. In turn, theory (even inchoate or implicit theory) dictates what it is considered important to observe or measure.

Because of this interdependence, self-consciousness regarding measurement practices seems essential if sound theoretical statements are to be made. The vast number of pages devoted to social science measurement issues indicates this self-consciousness is generally widespread. However, there are still some specialized subfields in which such scrutiny has been severely lacking. A case in point is "socio-network analysis," an interdisciplinary research area of which communication network analysis is a subtype. Before stating the problem more precisely, several definitions are needed.

A "socio-network" (or, more briefly, "network") may be defined as the set of relationships of a particular type (for example, communication, friendship, power, kinship) existing among a group of individuals. In network analysis these relationships may be identified via several distinctly different methods (compared by Davis, 1953; Edwards & Monge, 1976; and

Farace, Monge, & Russell, in press). However, the most common methods seem to use the reports of the network members themselves regarding those people with whom they share relationships of the type under study.

These relationships may be coded dichotomously (as being either present or absent) or they may be more precisely quantified in terms of their frequency, intensity, etc. In any case, for networks with more than three members many different configurations of the relationships comprising a network are theoretically possible. The particular topological configuration which does exist is called that network's "structure."

Structures are assumed to vary along many different theoretical continua, such as "connectiveness," called "dimensions." Since networks are composed of discrete, overt, countable, quantifiable entities (namely, the individual relationships existing between pairs of network members), the dimensions of structure are overtly describable. The mathematical formulae used as operational definitions of structural dimensions are here termed "indices" (called "metrics" by Richards, 1974, and others). An example of one such index is network "density" (Niemeijer, 1973)(called "connectedness" or "connectiveness" by other writers). It is computed as the percentage of theoretically possible relationships within a group which actually exist.

An index is here considered a "valid" measure of a particular dimension if its values <u>systematically</u> reflect variations in that dimension, either consistently increasing or consistently decreasing with increases in that dimension, that is, if it bears a monotonic relationship with the dimension under study.

Some dimensions (termed "theoretically distinct") are assumed capable of varying largely independently of one another and of entering into functional relationships with different non-structural variables. In this case, an index which covaries closely with (i.e., is a "valid" measure of) variations in one structural dimension may correlate poorly with variations in the other. This implies that index validity can be judged only with respect to a <u>specific</u> dimension of structure and not relative to an undifferentiated concept of "structure." That is, even the validation procedure must recognize the multi-dimensional nature of social structure.

Mathematical indices for measuring social structure have been used widely in fields as diverse as social anthropology, mathematical sociology, mathematical psychology, administrative science, and, of course, organizational communication. Yet, to date, amazingly little attention has been paid to their formal validation relative to the dimensions of structure they are employed to measure. The validation strategies seen in the structural literature are largely implicit and none of them has adequately appreciated the multi-dimensionality of structure.

Authors subscribing to a construct validation strategy have advocated selecting indices on the basis of correlations between those indices and measures of non-structural variables which are believed related to an undifferentiated structural variable. Such an approach may be adequate for strictly pragmatic purposes, such as the selection of a structural index to serve as a bell-weather of work group satisfaction. Its failure to enumerate specific dimensions of structure, however, makes this method seem uniquely unsuited for the more theoretical purpose of elucidating the relationships among structural and non-structural variables. Additional disadvantages of the method include (a) the inherent circularity of all construct validation approaches (Dubin, 1969; James, 1973); (b) the assumption that the subject population used in the validation study is essentially the same as all future populations on which the index is to be used (since correlations between structural and non-structural variables may change from subject population to subject population); (c) the still embryonic state of theory and the consequent possibility of error in choosing an appropriate non-structural variable; and (d) the possibility that the operational definition chosen for the non-structural variable might introduce substantial measurement error and spuriously deflate the correlation coefficient for the structure-to-non-structure relationship.

Researchers who have used previous face or content validation approaches have demonstrated a similar disregard for the multi-dimensionality of structure. While some have assessed index sensitivity to a dimension it is desired to measure, that is, sensitivity to a "target" dimension, most have neglected the equally important question of the degree to which an index's values may at the same time be affected by variations in non-target dimensions. Three different methods of face validation are found in the literature.

In the first face validation method (termed "dimensional specification" by Coleman, 1964) the researcher simply examines the index's computational formula and subjectively judges whether it "makes sense." In addition to this method's subjectivity, the difficulty in conceptualizing simultaneous variation along several dimensions (as would be required by a multi-dimensional approach) renders this method virtually useless to the validation problem posed here.

In the second method of face validation the researcher actually computes the index for those hypothetical networks which manifest extremely high or low values of the target dimension. While this method is more objective than the previous one, its disregard for the multi-dimensionality of structure is seen in its assumption that the correlation between an index's values and the amount of a particular structural dimension will not change substantially regardless of what values are assumed by other, non-target, dimensions.

Presently, the most rigorous form of face validation in the structural literature is Sabidussi's (1966) method, termed here "mathematical axiomatic deduction." In using this method the researcher formally enumerates the mathematical properties a true measure of a particular target dimension would have to have, and then evaluates indices believed to measure that dimention according to these criterial properties. While this method is rigorous as previously applied, it too has focused primarily on the sensitivity of an index to only one dimension (in this case, centrality). This method is potentially expandable to the multi-dimensional case, but the complexity of axiomatic systems for even one structural dimension make it too seem inadequate to resolve the validation problem posed here.

Yet the need for systematic validation is unmistakeable. In the absence of adequate validation data, researchers run the risks of both suboptimal use of data and potentially misleading results. Unhappily, examples of each of these may already be found in the literature (Edwards & Monge, 1975). The present paper describes a new type of face validation and reports the results of using it to evaluate 11 indices of communication structure.

Method

Related to Nosanchuk's (1963) method of comparing clique-identification procedures, the method used here in some ways resembles Bridgman's (1922) dimensional analysis. However, it is called "<u>multi</u>-dimensional analysis" (not to be confused with multidimensional scaling) to emphasize that, unlike previous methods, it evaluates indices with reference to <u>several</u>

dimensions rather than to only one.

The method involves the construction of sets of imaginary networks to serve as empirical standards. Its application here proceeded in four stages: (a) identification of dimensions which previous researchers have considered it important to measure; (b) construction of sets of networks differing incrementally along these dimensions; (c) selection of indices from among the dimensional categories; and (d) evaluation of each index's validity with respect to each dimension.

Identification of dimensions

The literature lacks an explicit list of theoretically distinct dimensions which researchers agree it is important to measure. Yet researchers obviously have theoretical dimensions in mind when they design and use indices. Consequently, a good source of these dimensions would seem to be the careful scrutiny of the indices themselves.

A careful examination of the most common indices of social structure (static structure only) in social anthropology, mathematical sociology, mathematical psychology, and organizational communication was undertaken to identify recurring measurement intentions of researchers in these disciplines.[2] These indices were found easily classifiable with reference to two dimensions (each having two subdimensions): Magnitude (with subdimensions of Size and Volume), and Disparity (with Concentration and Diameter).

The Magnitude dimension focuses primarily on the number of group members (i.e., network "Size") and the number of relationships among them (network "Volume"), having little concern with the distribution of those relationships within the network. In contrast, the Disparity dimension focuses on the distribution of relationships in terms of either their "Concentration," that is, the degree to which the relationships are concentrated upon one or a few individuals rather than distributed equally to all members; or the network's "Diameter," that is, the length of the shortest chain linking the two most "distant" individuals in the network. (Borrowed from mathematical topology (Flament, 1963; Harary, Norman, & Cartwright, 1965), the "distance" between two network members is measured as the least number of intermediary network members one would need to contact to pass a message between them.)

The reason they are listed as two dimensions with two subdimensions apiece rather than as four separate dimensions is that Size and Volume (and, likewise, Concentration and Diameter) do not seem "theoretically distinct" enough (see above) to warrant status as separate dimensions. Future empirical research may reveal important differences between the functional relationships involving Size and Volume (and likewise for Concentration and Diameter). However, currently lacking empirical aid of this kind, it seems best to minimize the number of separate structural dimensions being postulated.

The treatment of transitivity in the present analysis is a further example of this conservatism. Transitivity is the greater tendency for persons a and c to share a particular type of relationship (e.g., friendship, communication, etc.) with one another if such a relationship also exists between a and b and between b and c. Though transitivity seems intuitively to be a more complex theoretical continuum than is Magnitude, it has been associated with that dimension in the literature. In fact, indices of balance (a close relative of transitivity) have occasionally been used to measure network Volume (Luce, 1953). Consistent with this literature, transitivity is here treated as a part of the Volume subdimension. However, results reported here will be shown in the final section to raise doubts about the propriety of this grouping, and to suggest the possibility in the future of examining transitivity as a dimension in its own right.

Construction of Families of Hypothetical Networks

Nine sets, or "families," of hypothetical networks were constructed to serve as empirical standards representing each of the four subdimensions. In each of these families, a target subdimension was systematically varied from a minimum to a maximum value while the remaining three subdimensions were stabilized at known values. Two examples of each family appear in Figure 1.[3]

Insert Figure 1 about here

The first six families were designed as empirical standards for the Magnitude dimension, three families for the Size subdimension, and three families for the Volume subdimension. In recognition of the intimate relationship between Size and Volume, Volume was stabilized at a different (i.e., high, medium, or low) value in each of the Size families, and vice versa for the three Volume families (in which Size assumed values of 6, 10, and 14 nodes, respectively). In all six of these families, Concentration was minimized by assigning an equal number of links to all nodes in a particular network, and Diameter was minimized through the use of circumscribed configurations rather than open-ended branches (Harary, 1959).

Families 7, 8, and 9 were designed as empirical standards for the Disparity dimension. Two distinctly different types of Concentration were used in Families 7 and 8. The seventh family was designed to assess the sensitivity of an index to the positioning of a single link within the network. For this purpose, a "core" network of ten nodes having 8, 7, 6, 5, 5, 4, 4, 3, 2, and 0 links was created. To the tenth node was attached one end of the movable link. Nine networks were generated by successively attaching the other end of this link to each of the other nodes in the order that they are listed above. Because the indices gave identical readings for the networks in which the receiving nodes originally had the same number of links, one network for each of these two pairs was deleted, leaving a total of seven networks in this family. Throughout this family, Size was held constant at 10 nodes, and Volume at 23 links. ugh not held totally constant, varied by only om Diameter = 2 to Diameter = 3 links), a much smaller variation than exists in the Diameter family itself.

The eighth family was created to assess the sensitivity of the various indices to the degree of inequality in the distribution of links within the network, measured as the variance of the frequency distribution of links received per node. All frequency distributions were symmetric about a midpoint of five links per node. The variances found in this family are: 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, and 6.1. Size was held constant at 10 nodes, and Volume, at 25 links. Control of the Diameter subdimension was more difficult due to its intimate relationship with the Concentration of links in the network. This relationship is best shown by example. A network in which one node is directly linked to all others (i.e., one in which relationships are <u>concentrated</u> upon a particular node) will have a Diameter of only 2 even if no other links exist in the network. In a network of the same Size and Volume which lacks such a coordinating node, however, Diameter could be considerably larger than 2. In the present case, the effects of Diameter were minimized through the use of a special procedure for link assignment which connected nodes having relatively few links to those having relatively many. The success of this procedure in minimizing the variation of Diameter is demonstrated by the fact that Diameters in this family only varied by one link (from Diameter = 2 to Diameter = 3).

Finally, Family 9 represented [illegible] Diameter subdimension. In order to maximize variation in Diameter, the networks in this family (unlike previous families) were all composed of open branches. The first network in the family (with Diameter = 2) resembles a bicycle wheel. Subsequent networks were created by removing one spoke at a time and attaching it to the open end of another already centrally connected spoke until in the final network the links were stretched out end to end. Size was held constant at 10 nodes and Volume at 9 links per network. The close relationship between Diameter and Concentration precluded exercising total control over the Concentration subdimension. The variances of the link frequency distributions for these networks are 8.0, 6.6, 6.4, 4.6, 4.0, 3.6, and 3.4, a range of 4.6. While this range is relatively similar to the range of variances in the second Concentration family (which was 6.1), it was hoped that it was small enough that the indices would behave differently for the two families. As will be seen in the Results section, this expectation was fulfilled.

<u>Index Selection</u>

A set of indices was desired which showed promise as measures of communication structure. Due to the assumed bidirectionality of the communication relationship (Guimaraes, 1970), and the necessity to limit the scope of the study, only indices capable of distinguishing among strongly connected networks (i.e., networks in which all members are at least indirectly connected to one [illegible] consisting of bidirectional relationships were [illegible]. In order to assure their comparability, only indices calculated from interactional data were used (thus excluding the Size subdimension). With these constraints, indices were chosen to represent all three of the remaining subdimensions of structure: Volume, Concentration, and Diameter. Several indices were chosen from the same subdimension where its importance to network analysis or its popularity in prior research dictated that course.

Those chosen to represent the Volume subdimension were: density (Niemeijer, 1973); Coefficient A (Davis' 1967 measure of "clusterability"), and 3-balance (Cartwright & Harary, 1956), each of which combines the Size and Volume subdimensions of the Magnitude dimension.

Those selected for the Concentration subdimension were: Bavelas' (1950) global centrality; Zeisel's (1968) monopolization; Coleman's (1964) "h_1" measure of hierarchization; Monge's (1971) relative information; and Findley's (1966) group assimilation index. Finally, those selected for the Diameter subdimension were: Sabidussi's (1966) "trivial centrality," Mitchell's (1969) compactness; and Harary's (1959) global status. The computation formulae for all eleven of these indices are given in the appendix.

Evaluation of Index Validity

Index validity was defined above as the monotonic co-variation of an index with a target subdimension. Due to the p[illegible] unequal intervals [illegible]tween successive networks in the families, Spearman's rank order correlation was used to measure this monotonicity. An index which gave the same reading for all networks in a family was termed an "invalid" measure of the target subdimension; an index with a coefficient of +1.0 or -1.0 was "valid"; and an index with a coefficient in-between 0 and ± 1.0 was said to have "moderate validity" for that subdimension.

Since indices with only moderate val[illegible]ty would seem relatively useless either in measuring t[illegible]bdimension represented in the family or in avoiding its [illegible]founding influence when it was desired to measure other subdimensions, only those indices with perfect correlations were evaluated for their relative sensitivity to a particular subdimension. Index sensitivities were compared in terms of (a) the overall "shape" of the index-subdimension relationship for a particular [illegible]ly; and (b) the magnitude of the index's discrimination between the first and last networks in the family.

Wi[illegible] unequal intervals between successive networks in a family, even a maximally sensitive index would not have a linear relationship with a family of networks. For this reason, shape was evaluated in terms of both linear and quadratic components. Each network was assigned a numerical value equal to its ordinal position in its family, and these ranks were used in a polynomial regression. Shape was measured as the percentage of variance in the ordinal ranks which was accounted for by the combined linear and quadratic functions of the index. These percentages were then rank ordered within each family.

For the discrimination measure, each index's values were converted to *z*-scores, based on its mean and standard deviation for each family considered separately. The discrimination measure was the absolute difference between the *z*-scores for the first and last networks in the family. These differences were then rank ordered within each family.

Shape and discrimination are both desired properties, but they [illegible] covary perfectly. Thus, a separate coefficient was devised which adjusts the index's ranks on shape and discrimination for the discrepancy between those ranks. It is calculated as:

$$(\mathrm{Rank}_S - \mathrm{Rank}_D) + (\mathrm{Rank}_S)(\mathrm{Rank}_D),$$

where *S* stands for shape, and *D* stands for discrimination.

Results

As noted above, each index could be judged as either valid (with [illegible] order correlation of ±1.0), invalid (with rank order correlation of 0); or moderately valid (with rank order correlation in-between validity and invalidity). All results are summarized in Table 1.

Insert Table 1 about here

Numerical entries are relative sensitivity ranks (calculated only for the perfectly valid indices); "M" signifies moderate validity; "I" signifies total insensitivity or invalidity; and "undef." indicates that the index could not be calculated for all the networks in the family.

With respect to the Size subdimension, Indices 4, 5, 9, 10, and 11 appear to be valid; Indices 7 and 8 are invalid; Index 6 is undefined due to the low levels at which Concentration was stabilized; and Indices 1, 2, and 3 behave variably depending upon the Volume of links in the network. Of the valid indices for this subdimension, Index 10 appears to be the most sensitive, followed in order by Indices 4, 5, 11, and 9.

For the Volume subdimension, Indices 1, 9, and 11 appear to be valid; Indices 4, 5, 7, and 8 are invalid; Index 6 is undefined; and Indices 2, 3, and 10 behave variably depending on the Size of the network. Of the valid indices, Index 11 is the most sensitive, followed by Index 9 and Index 1.

Since the two types of Concentration are really quite different, their results are discussed both separately and collectively.

With respect to the relocation of a single link in the network, Indices 2, 3, 5, 6, 7, 8, and 11 are found to be valid indices. Of these indices, Index 7 is most sensitive, Indices 1, 2, 8, and 11 are tied for second place, and these are followed in turn by Index 6 and Index 5. Indices 4, 9, and 10 have moderate validity for this subdimension, and only Index 1 is found to be invalid for it.

For the variance of the frequency distribution o [illegible] Indices 4, 5, 7, and 8 appear to be valid indices, Index 5 being the most sensitive, then Index 8, Index 4, and Index 7. Index 1 is invalid; Index 6 is undefined; and Indices 2, 3, 9, 10, and 11 have moderate validity.

When the two families of Concentration are considered collectively, only Indices 5, 7, and 8 are found valid for both types, and only Index 1 is perfectly invalid for both. Of these, Index [illegible] is the most sensitive, followed by Indices 5 and 7.

Finally, with respect to Diameter, Indices 3, 5, 7, 8, 9, 10, and 11 appear to be valid measures, while Indices 1 and 2 are invalid, Index 4 is only moderately valid, and Index 6 is undefined. Of the valid indices, Index 11 is the most sensitive, followed in order by Indices 9, 10, 7, 3, 8, and 5.

Discussion

These results may be used in two ways: (a) to compare th validities and sensitivities observed here with those expected from the literature; and (b) to recommend specific uses of particular indices in future research.

For the first purpose, Table 1 was subdivided into columns, indicating the subdimensions being operationally defined and rows, indicating the subdimensional affiliations expecte for each index, based on the literature. The three partitions for which the column and row head... were labelled , ... Agreement with the literature was judged in terms of the number of numerical (rather than M, I, or undef.) entries each partition contained.

An examination of partition A, which pits alleged measures of Volume against the manipulation of Volume used here shows only Index 1 to be valid across all three Volume families. The fact that neither clusterability nor 3-balance is valid for all three families could be interpreted as evidence that they are simply not very useful indices. However, it seems more reasonable to interpret this as evidence that Volume and transitivity are not as closely related as the literature in the past has suggested. Perhaps these two indices would be perfectly valid for a family manifesting variations in transitivity alone, but resolution of this matter awaits further research.

A much better agreement with the literature occurs in partition B. In that partition, all five Concentration indices are found valid for at least one type of Concentration, and three of the five are valid for both types. The fact that Bavelas' centrality was found valid for the second type of Concentration substant... Flament's (19..3) claim that it is se...ive to the di...ion of links in a network.

Values in partition C are in perfect accord with the c...sification of these indices as measures of network Diameter.

In general, there seems to be a close correspondence between the index sensitivities that the literature suggests and those observed in these data. However, the presence of numerical entries in partitions other than A, B, and C shows that many of these indices have multiple sensitivities which are not mentioned in the literature. Since index values on one subdimension may actually be confounded by variation in another (theoretically distinct) subdimension, it is obviously important to keep these multiple sensitivities in mind when selecting or interpreting indices in research. The present multi-dimensional data seem uniquely well-suited for these activities.

It was noted above that an index with only moderate validity for a particular subdimension seems relatively less useful in either measuring that subdimension or avoiding its confounding influence when measuring other subdimensions. In contrast, the ideal index would be one whose validities are decisive, that is, a mixture of only ± 1.0 and 0 correlations. Only three indices satisfied this criterion in the present study. They were monopolization, relative information, and group assimilation.

The monopolization index was found to be a valid measure of Size, Concentration, and Diameter, but was perfectly insensitive to variations in Volume. Because these sensitivities cut across the supposedly theoretically distinct dimensions of Magnitude, and Disparity, this index might be of little general research value. However, to a researcher interested in measuring all subdimensions except Volume, this index might be quite useful. If values on this index were implicated in functional relationships with non-structural variables, a reasonable interpretation would seem to be that whatever structural subdimension was involved in a functional relationship, it was not Volume, and that it was probably either Size, or, Concentration, or Diameter, or some combination of them. These interpretations are stated either negatively or else probabilistically because of the possible existence of additional structural dimensions not yet identified. This issue is addressed in more detail later in this section.

The other two indices, relative information, and group assimilation, were found to be perfectly valid for the two Disparity subdimensions, and perfectly insensitive to both of the Magnitude subdimensions. This suggests their possible utility in measuring the Disparity dimension free from confounding by the Magnitude dimension. If either of these indices is implicated in a functional relationship with a non-structural variable, the appropriate interpretation would seem to be that the structural subdimension involved in the observed relationship was neither Size nor Volume, and that it was probably either Concentration or Diameter or some combination of the two.

Differences in the relative sensitivites of these two indices suggest an even more sophisticated basis for index selection. A researcher wishing his index to be more sensitive to Concentration than to Diameter might select group assimilation rather than relative information. However, the frequently small differences in the shape measure and the fact that there were many tied ranks makes this inadviseable on the basis of the present data alone.

This study has proposed and employed a new method for the validation of structural indices. This method has several importand advantages over previous methods. The first advantage is in its use of hypothetical networks rather than actual socio-networks. This allows greater variation in the target subdimensions than would be found in natural settings. Additionally, it enables much greater control over the observational situation. In the natural setting, afterall, many subdimensions would vary at once, leaving no possible way of systematically ordering them. A second advantage is that this method provides data-based (rather than merely intuitive) recommendations which have actual practical utility. One final advantage is its heuristic value. Since its use requires the specification and operational definition of target as well as non-target subdimensions, it openly encourages the clarification of the Structure variable and its most potent dimensions.

While several weaknesses may be noted also, none of them seems inherent in the method itself (as were the shortcomings of most previous methods), but only in its application here. The first of these concerns the inadequate research enumerating theoretically important dimensions of structure. To the degree that the present list is incomplete, and unspecified dimensions are left free to vary, the index sensitivities reported through the use of this method may not be entirely correct. In order to avoid a proliferation of unneeded dimensions, however, a conservative approach seems also needed. This method need not be limited by such conservatism, however. Its results may well suggest additional dimensions needing further study, as was shown in the case of transitivity. While clearly a bootstrap operation, this approach seems to have considerable promise.

A second weakness with the current application of this method involves the present choices of stabilizing values for non-target subdimensions. As Coleman's hierarchization index illustrates, index values may be confounded by non-target subdimensions even if those subdimensions are held constant. Thus, in the present case, each time Concentration was minimized, this index was undefined. To minimize a systematic bias of this sort, it is suggested that future researchers select stabilization values at random from a set of logistically possible combinations of them.

A final weakness is the fact that the present application involved variation on only one subdimension at a time. The real world of structure is full of simultaneous variations of various dimensions. To the degree that they are theoretically distinct, the validity of an index for the target subdimension will be lessened, hence potentially lessening the pragmatic utility of the recommendations made from these data. Thus, it is recommended that future applications of this method involve the simultaneous variation of multiple subdimensions.

In addition to making these suggested changes in future applications of this method, it is hoped that future researchers will evaluate more and different indices, and adapt additional methods to the multi-dimensional validation of structural indices. Sabidussi's (1966) method seems particularly promising in this regard since it seems capable of indicating <u>why</u> indices measure what they do.

Though the systematic validation of structural indices is currently lacking, it is hoped that its importance will soon be appreciated, and that these and related approaches will be expanded to illuminate the measurement capabilities of many promising indices. Once this is accomplished, theorizing regarding socio-networks generally, and communication networks in particular, will seem at last free to advance with well justified self-confidence.

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otnotes

[1]This resear nsored by the Organizational Effectiveness Research Programs Naval Research (Code 452), under Contract Number N00014-75- er R. Monge, Principal Investigator.

[2]This review ble upon request from the authors.

[3]While space prevent the inclusion of all 60 networks here, the full set able on request from the authors.

TABL[illegible]

Tr[illegible]s and Relat[illegible] Sensitivities [illegible] Each Index for Each Subdimension

[illegible]dex	MAGNITUDE DIMENSION: Size, low vol.[a]	Size, mod.	Size, high vol.	Size, comb.	Volume, n=6	Volume, n=10	Volume, n=14	Volume, comb.	DISPARITY DIMENSION: Concentration, 1	Concentration, 2	Concentration, comb	Diameter
[illegible]nsity	[illegible]	[illegible]	I	M[c]	2		2	5	I	I	I	I
[illegible]ster-ability	I	[illegible]	I	M	I	M	M	M	2	M	1	I
[illegible]-balance	M	5	I	M	M	M	M	M A	2	M	1	4
[illegible]velas	2	2	2	2	I	I	I	I	M	3	M	M
[illegible]nopoli-zation	1	4	2	3	I	I	I	I	4	1	2	6
[illegible]rarchi-zation	—	—	—	undefined[d]	—	—	—	—	3	und.	und.	und.
[illegible]mation Theoretic	I	I	I	I	I	I	I	I	1	4	2	3
[illegible]up Assi-milation	I	I	I	I	I	I	I	I	2	2	1 B	5
S[illegible]dussi	6	6	4	5	2	2	1	2	M	M	M	2
[illegible]Compactness	3	1	1	1	M	M	M	M	M	M	M	3
[illegible]ary	5	3	3	4	1	1	2	1	2	M	M	1 C

[a] [illegible]umn entries are relative sensitivity ranks for valid indices (i.e., those having perfect [illegible]tions) for a particular subdimension.

[b] I designates invalidity for the target subdimension.

[c] M designates moderate validity for the target subdimension.

[d] "und[illegible]d" or "undef." indicates the index was not calculable throughout the family.

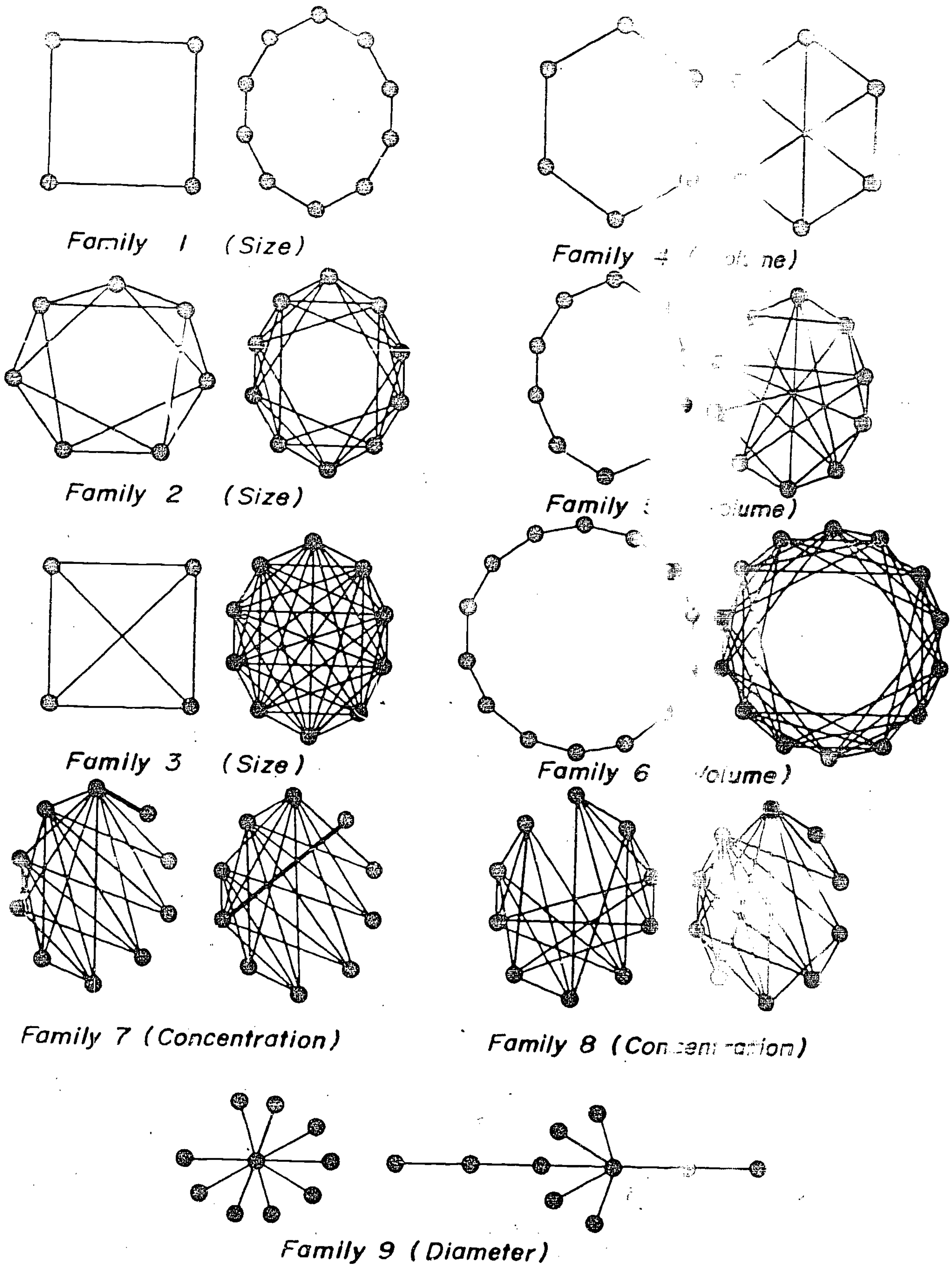

FIGURE 1. Beginning and intermediate networks for each of nine families.

[illegible]

[illegible] the [illegible]

For [illegible] of the indic[illegible] [illegible]llowing equ[illegible] hold:

n = the number o[illegible] the network

$\sum X_j(\text{a}$[illegible] = th[illegible] node $\underline{i}$ i[illegible]ncy matr[illegible]

$\sum_{j=1} X_j(\text{dist})$ = t[illegible] node $\underline{i}$ [illegible]ce matrix

$\sum_{i=1}^{n} \sum_{j=1}^{k} X_{ij}$[illegible] = the [illegible] all rows i[illegible]acency matrix

$\sum_{i=1}^{n} \sum_{j=1}^{k} X_{ij}(\text{dist})$ = the tot[illegible] of all rows in [illegible]tance matrix

N_i = the number of 3-cycles having $\underline{i}$ posi[illegible] l[illegible]ks

	Index	Cited	Source	Formula
1	Density	p. 29	N[illegible]steiger, [illegible]7[illegible]	[illegible]
2	Cluster-ability	p. 32	[illegible], 1967 (see [illegible]belson, 196[illegible])	[illegible]
3.	[illegible]lance	p. 31	Cart[illegible]right & Har[illegible], 1956	[illegible]
4	[illegible] centrality	p. [illegible]	Bave[illegible], 1950	[illegible]

[illegible]	Cite	Source	Formula
5. [illegible]pol[illegible]–[illegible]on	p. [illegible]	[illegible] 1968	$\frac{\sqrt{\sum_{i=1}^{n}\left[\sum_{j=1}^{k}X_{ij(adj)}\right]^2}}{\sum_{i=1}^{n}\sum_{j=1}^{k}X_{ij(adj)}}$ Exception: When the quantity $\sum X_{j(adj)}$ equals 1, [illegible] appears only in [illegible]e denominator.
6. "h"	[illegible]. 29	[illegible]oleman, 1964	$1 - \frac{z^*}{\sum_{i=1}^{n}\sum_{j=1}^{k}X_{ij(adj)}}$ [illegible] z^* equals: $\frac{n-2}{[illegible]}\left\{\left[\frac{\sum_{j=1}^{k}X_{j(adj)}}{\sum_{i=1}^{n}\sum_{j=1}^{k}X_{ij(adj)}} - \frac{1}{n}\right]\right\}^2$
[illegible] Relative Information	[illegible]	Monge, [illegible]71	$\frac{H_{obtained}}{H_{maximum}}$ [illegible]here: $H_{max} = \log_2 n$ $H_{[illegible]} = [illegible] \sum_{i=1}^{n} p_i \log_2 p_i$ $p_i = \frac{\sum_{j=1}^{k}X_{j(adj)}}{\sum_{i=1}^{n}\sum_{j=1}^{k}X_{ij(adj)}}$

I[illegible]x		Source	[illegible]rmul[illegible]
.	[illegible]roup Assi-milati[illegible]n	Fin[illegible]ey 1[illegible]66	[illegible] $- \frac{[illegible]^2}{[illegible]^2}$), where [illegible] : $\frac{[illegible]b^2 - a^2}{[illegible])\left[[illegible]-1) - \frac{[illegible]}{[illegible]}\right] a^2}$ [illegible] $= \sum_{j=1} [illegible](a[illegible])$ $b = [illegible]\sum_{j=1} [illegible]j(adj[illegible])$
9.	Sab[illegible]dussi's Trivial Centrali[illegible] [illegible]	Sabidussi, 19[illegible]6	$\frac{[illegible]}{\sum [illegible](dist)}$ [illegible] $\sum_{j=1} j(di[illegible])$ is [illegible] smallest row [illegible] the distance m[illegible]ri[illegible]
.	[illegible]ctne[illegible]	[illegible]tchell, [illegible]69	$\frac{n(n-1) + [illegible]\sum_{j=1}^{k} [illegible]j([illegible])}{2[illegible]}$, [illegible] is the maxi-[illegible] cell entry in [illegible]e distance matrix
11.	Har[illegible]'s Gro[illegible] [illegible]tus	Harary, 1959	$\frac{[illegible]}{[illegible]}\sum_{j=1}^{k} [illegible]j(dist)$