A Pascal program to generate objective indices of group or organizational structures

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As an adjunct to developing a theory of structural roles, a mathematical model of group or organizational structure was developed (Oeser & Harary, 1962, 1964; Oeser & O'Brien, 1967). This paper briefly describes the model, the generated quantitative structural indices, and a Pascal program to compute the indices.

The Mathematical Model

Organizational or group structure is described by three elements: persons (h), positions (p), and tasks (t), and the five relations between these elements. The relations are the informal relations between persons (H-H), the assignment relations between persons and positions (H-P), the power relations between positions (P-P), the allocation relations between positions and task (P-T), and the precedence relations between tasks (T-T). The structure may be represented schematically as in Figure 1. Each element is represented by a dot, and the relations are represented by directed arrows between the elements. Figure 1 represents a three-person (h_1, h_2, h_3), three-position (p_1, p_2, p_3), three-task (t_1, t_2, t_3) group. Each person is assigned to one position, and each position is allocated to one task element. Position p_2 has legitimate power over positions p_1 and p_3 and this is represented by directed lines from p_2 to p_1 and p_3 . The arrows between the task elements indicate that the group is performing a coordinative or assembly-line-type task. Person h_1 is assigned to position p_1 and completes the first part of the task, t_1 , which is then passed to person h_2 at position p_2 , and so on. The informal relations or communication network between persons is similarly represented by directed lines between the person elements (h_1, h_2, h_3).

The set of five relations may also be represented in matrix form. The matrices for the set of relations described in Figure 1 are presented in Table 1. A matrix entry of 1 indicates the presence of a relation between two elements, and an entry of 0 indicates the absence of a relation. Matrix entries can also be a decimal value greater than 0 to indicate both the presence and strength of a relation. The organizational or group structure is represented in matrix form because matrix algebra is used to generate quantitative structural indices.

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Figure 1. Schematic representation of a basic three-person (h_1, h_2, h_3), three-position (p_1, p_2, p_3), and three-task (t_1, t_2, t_3) group structure. R0 represents the informal relations between persons (H-H), R1 the power relations between positions (P-P), R2 the precedence relations between tasks (T-T), R3 the assignment relations between persons and positions (H-P), and R4 the allocation relations between positions and tasks (T-T).

Structural Indices

As an example of the type of indices that can be generated, we will consider a measure of potential influence. A person's potential influence is defined as the number of opportunities that that person has to shape the task-relevant behavior of the other group members or co-workers (O'Brien, Biglan, & Penna, 1972). In terms of the model, a person's potential influence is defined as the number of paths from that person to all elements in the task system, weighted by the total number of sequences connecting all persons to all tasks (O'Brien et al., 1972). The number of paths connecting persons to task elements is represented by the M matrix. The M matrix for Figure 1 is:

$$M = \begin{array}{c|ccc} & t_1 & t_2 & t_3 \\ \hline h_1 & 3 & 4 & 6 \\ h_2 & 4 & 7 & 11 \\ h_3 & 2 & 3 & 6 \end{array}$$

This matrix shows that there are three paths from person h_1 to task t_1 . From Figure 1, these paths are:

- (1) $h_1 \rightarrow p_1 \rightarrow t_1$
- (2) $h_1 \rightarrow h_2 \rightarrow p_2 \rightarrow p_1 \rightarrow t_1$
- (3) $h_1 \rightarrow h_2 \rightarrow h_1 \rightarrow p_1 \rightarrow t_1$.

Similarly this M matrix shows that there are four paths from h_1 to t_2 , six paths from h_1 to t_3 , six paths from h_3 to t_3 , and so on. The number of paths is affected by restrictions imposed on the maximum length of paths and the number of loops allowed in each path. For very simple structures, the M matrix can be computed by simply counting the number of paths from persons to tasks. For more complex structures, matrix algebra is required to derive the M matrix from the five matrices described in Table 1. The algebraic methods and the restrictions imposed on path length were fully discussed by O'Brien et al. (1972). The potential influence of each person is given by:

$$I_{h_i} = \frac{\text{sum of entries of Row}_i \text{ of M matrix}}{\text{sum of all entries of M matrix}}.$$

Therefore the potential influence of person h_2 in Figure 1 would be:

$$I_{h_2} = \frac{\text{sum of entries of Row}_2 \text{ of M}}{\text{sum of all entries of M}} = 22/46 = 0.48.$$

As well as potential influence, measures of potential participation (O'Brien & Gross, 1981), task collaboration,

and task coordination (O'Brien, 1968; Witz & O'Brien, 1971) have been derived. A collaborative task is one that requires persons to work simultaneously on the same task element, and a coordinative task is one in which work is affected by the work of preceding persons. A group decision-making task is an example of a collaborative task, and an assembly-line task (as in Figure 1) is an example of a coordinative task. In terms of the model, task collaboration refers to the extent to which different positions are allocated to the same task element, and task coordination refers to the extent to which task elements allocated to different positions need to be sequenced by definite precedence relations. Task collaboration is derived from the PT matrix, and the measure of task coordination is derived from the PT and TT matrices (O'Brien, 1968; Witz & O'Brien, 1971).

Like potential influence, the potential participation index is calculated from the M matrix, except that the row sums are weighted by the maximum participation possible for a given set of persons, positions, and tasks (O'Brien & Gross, 1981). The size of the weighting varies with the length of the paths allowed and with the number of loops allowed in each path. O'Brien and Gross (1981) described seven different weights and the formulas for their calculation. This use of variable weights means that the potential participation measure is comparable across structures that vary in the number of persons, positions, and tasks.

The mathematical model and the indices derived from it are useful research tools in the study of organizational behavior. Potential influence has been used as a measure of situational favorability in the contingency model of leadership (Kabanoff, 1981; O'Brien, 1969), and it has been suggested that the indices be used as measures of the "situation" in expectancy models of performance and motivation (Mitchell & Biglan, 1971), and as preperformance measures of group process variables (Shiflett, 1979). However, mathematical complexity and computational difficulties are likely to deter potential users. With small groups ($N < 4$) and simple relations (matrix entries of 0 or 1), the computation of indices is tedious and prone to error, but when personal or personality variables (e.g., age, ability, or control) are used as measures of the strength of the various relations, or the model is applied to large groups or organizations ($N > 50$), then a computer program becomes essential.

A Pascal Program

The program described below is designed to compute, for a given structure, the potential influence of each person, an unweighted potential participation index, the seven weighted measures of potential participation described by O'Brien and Gross (1981), and the measures of task coordination and task collaboration.

Input. Before this program can be used, each of the five matrices (HH, HP, PP, PT, TT) must be stored in a separate data file with each matrix entry separated by at least one blank space or carriage return (i.e., freefield). The program prompts for the names of these data files

Table 1
Matrices and Their Program Labels for the
Five Relations Shown in Figure 1

Relation	Matrix	Program Label
	$\begin{array}{ccc} & h_1 & h_2 & h_3 \\ h_1 & 0 & 1 & 0 \\ h_2 & 1 & 0 & 1 \\ h_3 & 0 & 1 & 0 \end{array}$	Matrix A
	$\begin{array}{ccc} & p_1 & p_2 & p_3 \\ h_1 & 1 & 0 & 0 \\ h_2 & 0 & 1 & 0 \\ h_3 & 0 & 0 & 1 \end{array}$	Matrix B
	$\begin{array}{ccc} & p_1 & p_2 & p_3 \\ p_1 & 0 & 0 & 0 \\ p_2 & 1 & 0 & 1 \\ p_3 & 0 & 0 & 0 \end{array}$	Matrix C
	$\begin{array}{ccc} & t_1 & t_2 & t_3 \\ p_1 & 1 & 0 & 0 \\ p_2 & 0 & 1 & 0 \\ p_3 & 0 & 0 & 1 \end{array}$	Matrix D
	$\begin{array}{ccc} & t_1 & t_2 & t_3 \\ t_1 & 0 & 1 & 0 \\ t_2 & 0 & 0 & 1 \\ t_3 & 0 & 0 & 0 \end{array}$	Matrix E

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Matrix A is from file A1
Matrix B is from file B1
Matrix C is from file C1
Matrix D is from file D1
Matrix E is from file E1

Matrix A :
0.000    1.000    0.000
1.000    0.000    1.000
0.000    1.000    0.000

Matrix B :
1.000    0.000    0.000
0.000    1.000    0.000
0.000    0.000    1.000

Matrix C :
0.000    0.000    0.000
1.000    0.000    1.000
0.000    0.000    0.000

Matrix D :
1.000    0.000    0.000
0.000    1.000    0.000
0.000    0.000    1.000

Matrix E :
0.000    1.000    0.000
0.000    0.000    1.000
0.000    0.000    0.000

Coordination Index =    0.111
Collaboration Index =    0.000

*****
Model : A'BC'DE'

Output matrix :
3.000    4.000    6.000
4.000    7.000    11.000
2.000    3.000    6.000

Participation Matrices :
P0      P1      P2      P3      P4      P5      P6      P7
13.000   0.023   0.160   0.241   0.481   0.722   0.212   0.041
22.000   0.039   0.272   0.407   0.815   1.222   0.359   0.070
11.000   0.019   0.136   0.204   0.407   0.611   0.180   0.035

Influence Matrix :
0.283
0.478
0.239

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Figure 2. Sample output for the standard model A'BC'DE' for the structure represented in Figure 1 and the matrices described in Table 1.

and stores their contents in matrices A, B, C, D, and E, respectively. The program then asks for the name of the output file. Next, the program prompts for the matrices that are to be processed, processes these matrices, and writes the results to the output file. If the user requests, instructions are provided on the terminal at each stage of input. Complete step-by-step instructions are provided in the manual.

Output. Sample output is shown in Figure 2. The output includes the names of the input files, the contents of the input files, the coordination and collaboration indices, the output (M) matrix, the potential participation measures, and the potential influence measures. P_0 is the set of unweighted potential participation measures, and P_1 to P_7 are the seven weighted potential participation measures described by O'Brien and Gross (1981). The output also notes the model or combination of matrices used to generate the indices. In Figure 2, the model is A prime, B, C prime, D, E prime (A'BC'DE'). Priming or not priming the various matrices defines the maximum length of the paths from the persons to the tasks (see O'Brien et al., 1972). The A'BC'DE' model is always used to compute the indices described above. Other models, such as A'BC' or ABCDE, can be processed by the program, but the usefulness of such models and their associated indices is an

empirical question that can be considered by users if they desire.

Program Language and Requirements. The program is written in Pascal, and the only departures from standard Pascal (Jensen & Wirth, 1978) are the use of the underscore character ("_") in long variable and procedure names, and the use of variable names that are unique after 8 but fewer than 32 characters. The program was developed (and has been used exclusively) on a Prime 850, 5-MB, 32-bit machine, but any machine that can accommodate the 700 lines of program code and the input file arrays should be able to run this program satisfactorily. However, it is doubtful whether an 8-bit machine can produce indices for large structures with the program (e.g., 50×50). The maximum size of the structure that can be processed (and therefore the memory requirements) is adjusted by changing the constant declaration `maxarraysize` on page 1 of the program.

Availability. A program listing (or copy of the program) and user manual may be obtained at no cost from John Crosbie, Psychology Discipline, School of Social Science, The Flinders University of South Australia, Bedford Park, South Australia, Australia 5042. If a copy of the program is required, send a tape and details of the preferred format in which it is to be written.

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