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A PCANS Model of Structure in Organizations

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Abstract

We present a network based approach to characterize C^2 architectures in terms of three domain elements - individuals, tasks, and resources. Characterizing the possible relations among these elements results in five relational primitives - Precedence, Commitment of resources, Assignment of individuals to tasks, Networks (of relations among personnel) and Skills linking individuals to resources. We demonstrate the utility of this model for recharacterizing classical organizational theory and for generating a series of testable hypotheses about C^2 performance.

1. Introduction

This paper proposes that organizations, and in particular their C^2 architecture, can be better understood, analyzed and even managed by understanding the complex structure of interdependencies that exist within its boundaries. This is not a new claim. Galbraith [1977], Thompson [1967], Perrow [1970], and Pfeffer and Salancik [1978] have all suggested ways in which such technological and human interdependencies can be predicted and used to further our theoretical understanding of organizational phenomena. While these models have been useful, they are abstract and nonspecific on how the interdependencies can be assessed. We propose that these earlier models can be enhanced with formalisms incorporating the inherent complexities of these interdependencies.

Specifically, we propose a set of three domains in organizations that are universal: 1) Organizations are composed of individuals (I)[1] ; 2) These individuals are assigned tasks (T) to accomplish as part of their membership in the organization; and 3) there is a specification of resources (R)[2] that are required to accomplish certain tasks. All three domains exist within any C^2 architecture.

In order to characterize and understand the C2 architecture of a unit, to understand the structure of an organization's set of interdependencies, it is necessary to understand how various elements of these domains map onto one another. For example, certain personnel are assigned certain tasks; different personnel have access to different resources required for those tasks; certain personnel have access to (are connected to) each other; different tasks must be accomplished before other tasks can begin; etc. It is the specification of these

[1] Although we have used the term individual, the model we define is equally valid when these "individuals" are more generally described as DMUs (decision making units). DMUs can be either individuals, groups, combination of humans and intelligent agents, etc. The point is that this unit acts from a task based perspective as a single decision making unit.

[2] At the level of detail appropriate to this approach resources can be alternatively characterized as the individual's specific skills, their access to particular equipment, or some combination of the two.

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mappings of particular objects in each domain onto one another that we take as the primitives in our formalisms, that we use to understand the C^2 architecture of the unit in a more complete way than has been possible heretofore.

2. The PCANS Model

To be specific, we propose that all organizations are structured along these three domains, Individuals, Tasks and Resources. The C2 architecture of the unit can be characterized as a mapping of the elements of these three domains onto one another in meaningful ways. We begin by proposing a set of five primitive relations among these three domains of elements.

Precedence (P): There is a temporal ordering of tasks in organizations. That is, some tasks are completed before other tasks begin. For example, marine based units must take the beach before they can move inland. PERT charts are one type of mechanism that provides a visual map of these temporal dependencies. Thompson [1967] used temporal ordering of tasks as a key to defining types of interdependencies -- for example, pooled interdependence, with no temporal ordering; and sequential interdependence, where task A had to precede task B. We refer to this temporal ordering as a Precedence mapping, a set of ordered pairs of tasks (T1, T2) which designate that Task 1 precedes Task 2. This precedence relation is defined by the matrix P where $P_{ij} = 1$ iff task i must precede task j; else $P_{ij} = 0$. P then is of order TxT.

Commitment of resources (C): Certain tasks require certain resources. For example, analysis of a particularly complex research problem may require time on a super computer; a stock trade may require a seat on the NYSE; maintaining an Air Force F-15 may require access to a spare parts depot, shooting down a ballistic missile requires an ABM. That is, the organization must commit certain resources to a task in order for it to be accomplished. The mapping of these resources (R) onto these tasks (T) describes these dependencies. Specifically, we define these commitments by a matrix C where $C_{ij} = 1$ iff resource j has been committed to task i; else $C_{ij} = 0$. C then is of order TxR.

Assignment of personnel to tasks (A): Personnel are assigned to accomplish certain tasks. Sometimes these assignments are distinct (for example, in a joint task force one commander may be in command of all amphibious based assaults and another in command of all air based assaults); sometimes these assignments are diffuse (several battalions are assigned to the same task). These assignments have the effect of giving particular personnel (or DMUs) responsibility for completing these tasks. We define these assignments by a matrix A where $A_{ij} = 1$ iff individual i is assigned to task j; else $A_{ij} = 0$. A then is of order IxT.

Network (N): Personnel have differential access to each other. This access is sometimes determined by formal arrangements (such as the chain of command or the formal org chart), but often it is the informal relationships that prove to be critical in how the organization functions as a whole [Krackhardt and Hanson, 1993]. Of all the primitives, the Network is the one most familiar to organizational theorists. The Network itself is often considered the true structure in an organization [Burt, 1982; 1992]. In keeping with the tradition of network analysis in organizations, we define these relations among personnel by a matrix N where $N_{ij} = 1$ iff individual i has a relationship directly with individual j; else $N_{ij} = 0$. N then is of order IxI.

Skill (S): Personnel bring to their work different abilities and resources. Some of these they develop individually through education or training; some are provided to them by the organization, such as access to special equipment or financial resources. By "skill", we mean to include all such resources that an individual may hold or have access to. We define skill, then, by a matrix S where $S_{ij} = 1$ iff individual i has direct access to or control over resource j; else $S_{ij} = 0$. S then is of order IxR.

This completes the set of five primitives: Precedence, Commitment, Assignment, Network and Skill -- or PCANS for short. These primitives are summarized in Table 1.

Table 1. PCANS Primitives

Assign	A	IxT
	i->t = person i is Assigned task t	
Skill	S	IxR
	i->r = person i has Skill defined by r	
Commit	C	TxR
	t->r = resource r is Committed to task r	
Network	N	IxI
	i1->i2 = person i1 is connected to person i2	
Precedence	P	TxT
	t1->t2 = task t1 must be done before t2	

There is a considerable amount of information contained in these primitives by themselves. But, as we shall see shortly, these five relations are just the tip of the iceberg. For example, each relation has a transpose, designated with '. In addition we can differentiate and idea or desired state (marked with a *) from an actual or observed state. Thus, we have the following 20 primitive relations:

P C A N S
P' C' A' N' S'
P* C* A* N* S*
P*' C*' A*' N*' S*'

3. Compound Words

One of the traditions in network analysis is to combine primitives mathematically into compound relations, deriving new relations that may hold new insight into the structure of the system as a whole [Wasserman and Faust, 1994; Lorraine and White, 1971; White, Boorman and Breiger, 1976]. For example, suppose we were to start with a simple relation K, "is a child of," such that Kij = 1 iff person i is a child of person j. If we perform a simple matrix multiplication of K on itself, then the result (=KK) would be a matrix that could be interpreted as "is a child of a child of", or "is a grandchild of". That is, if $KK_{ij}=1$, then i is a grandchild of j.

Another useful mathematical function for such relations is the transpose, where the (i,j) values of a matrix are switched with the (j,i) values. The transpose of matrix K is designated K' and may be interpreted as "is a parent of." That is, $K'_{ij} = 1$ iff i is the parent of j; else $K'_{ij} = 0$. K'K' is the matrix that identifies grandparents. If we combine the transpose with the original matrix, we can identify other important relations. For example, KK' can be thought of as "is a child of a parent of", or, in other words "is a sibling of". K'K, on the other hand, defines "is a parent of a child of", or, in other words "is a spouse of." By tradition, when these primitive relations, such as K, are multiplied together in this way, the results are called "words" [Lorraine and White, 1971].

These same mathematical manipulations can be applied with equal ease and utility to the PCANS primitives. For example, if we multiply a friendship matrix N by itself, we get a matrix NN whereby NNij tells us whether j is a "friend of friends" of i. If we multiply A by A', we get a AA', where AA'_{ij} equals the number of tasks that individuals i and j are assigned to in common. There are restrictions on what words are legal (the rules of mathematics prohibit, for example, multiplying P by N because they are not conformable, that is the number of columns in P does not match the number of rows in N). But we are presented here with a vast array of possibilities with which we may describe, analyze, and even control organizations.

For example, the P relation by itself describes sequential interdependence among