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Nolan's stage model of computing growth has been widely cited in the literature on information systems, but surprisingly has not received a careful analytical review. This paper reviews the Nolan model, assessing its development, structure, sensibility, and place within evolution explanations in the social sciences. The model itself is shown to be an evolving concept, responding to changes in the field of information systems and organizations. A critical assessment of the model's major assumptions and claims reveals that many of these are empirically weak and intuitively implausible, despite the intelligent insights that went into constructing the model. The model is shown to be largely an evolutionistic model rather than an evolutionary model, thus making it subject to many of the problems of evolutionist models. However, some aspects of an evolutionary theory are found in the model, making it a useful contribution to the continuing effort to improve understanding of the processes of change in organizational information systems over time.

EVOLUTION AND ORGANIZATIONAL INFORMATION SYSTEMS: AN ASSESSMENT OF NOLAN'S STAGE MODEL [1]

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INTRODUCTION

The best known model of evolution related to organizational information systems is the "stage" model of Richard Nolan. This model, which first appeared in print in 1973, has been cited extensively as the major statement about the growth of information systems in organizations. From its beginnings as a tentative hypothesis (Nolan, 1973), it has become regarded as an empirically grounded theory (Nolan, 1979) and an accepted description of how changes in organizational information systems take place over time (Ahituv and Neumann, 1982; Alter, 1980; Ein-Dor and Segev, 1978; Keen and Scott Morton, 1978; McKenney and McFarlan, 1981; Rockhart and Flannery, 1981).

Despite the widespread attention Nolan's model has attracted, it has never been subjected to a careful analytical review in the published literature. Given the importance of the model in the information systems field, and the interpretations of data and prescriptions for management based upon it, such a review is overdue. This paper reviews the Nolan stage model in light of the basic structure of the model itself, and its use as an evolution theory in the context of evolution explanations in the social sciences of which it is a part. It concludes with an assessment of the model's practical utility as a descriptor of the process of change in organizational information systems over time.

THE NOLAN MODEL [2]

The Nolan model does not appear in the literature as a single model, but in a number of versions developed between 1969 and 1979. The model originated in discussions between Nolan, Neil Churchill and F.Warren McFarlan between 1969 and 1971, and was subsequently elaborated in Gibson and Nolan (1974), Nolan (1977) and Nolan (1979). Although basic aspects of the model have remained the same over time, significant elaborations of the earlier model have appeared in later versions. In this section we examine the development of the model through these versions.

The 1973 Version

The core concept behind the model first appeared in print in Nolan's 1973 article in Communications of the ACM. The model was presented as a hypothesis, but it was grounded in observations and discussions with managers in three firms. The experiences of these firms form the base of the "stage theory" of computing growth intended to meet two conditions adopted from Kuznets (1965): identification of distinct and empirically verifiable characteristics of change; and detailed specification of the characteristics of succession whereby one stage moves to the next.

To capture the characteristics of change in computing in organizations Nolan made the assumption that changes in budgets for computing can serve as a surrogate measure for change in a wide array of environmental and technical variables, including changes in industry conditions, corporate sales, organizational strategy, management practices, and uses of computer technology (Nolan, 1973:401). Plotting the changes in budgets for computing in the three firms revealed that budgets seemed to grow according to an S-shaped curve. This led to a second major assumption: that the turning points in the budget curve (shown in Figure 1) are transition points between stages of growth. The turning points A, B, and C in Figure 1 break the S-curve into four stages. From here Nolan made a third major assumption: that these stages "capture the central tendencies" of the major tasks in the management of computing: planning, organizing, and controlling. Working backward, the logic of the model runs as follows: the major activities in the management of computing are identifiable in stages that correspond to periods of stability along the growth path of computing use, traced by change in computing budgets which acts as a surrogate measure of environmental and technical variables that make up the computing phenomenon in an organization. Management practices related to computing are thus explained as responses to environmental and technical changes. (The complete model based on all versions is shown in Figure 2.)

Briefly, Nolan's four stages from the 1973 model are:

Initiation: Introduction of computing into the organization to meet basic needs; slow growth in use; beginning of problems caused by computing's role as a "change agent;" little management response to these problems; decentralized control; minimal planning.

Contagion: Top management commitment to exploiting computing's potential plus great expectations among users brings major growth in computing use; costs rise rapidly; a cost crisis stimulates top management to search for controls to contain costs; centralization begins; planning remains weak.

Control: Top management institutes cost control measures; planning becomes a major priority; the computing function is centralized; the DP manager's position is raised in the organizational heirarchy; priority setting is mandatory; standards are established for programming, documentation and operations; chargeout systems are adopted to impose market-like constraints on use; controls often prove to be too stringent, resulting in failure to exploit the potential of computing or meet user expectations.

Integration: Controls refined to allow exploitation of computing without runaway costs; planning well established; users are more knowledgeable and capable in their uses of combenefit operations become more rational; economic analyses (eg. cost- analysis) used to set priorities for new systems; chargeout systems modified to ease restriction on use; system analysts sometimes decentralized to user departments to encourage improved systems development; centralization/decentralization decisions now made in light of organizational and business strategy; growth slows markedly, but new investments bring greater marginal benefits.

Nolan claimed in this article that no organizations had reached the Integration stage, but that they would begin to do so soon, and growth in computing costs would begin to decline as they did so. Using the assumption that the stages capture the management tasks of control, organization and planning, Nolan summarized the implications of the model: control is lax in stages I and II; reactionary and overdone in Stage III; and refined and effective in Stage IV.

The 1974 Version

Although Nolan specifically states that the model does not assert cause and effect relationships (Nolan, 1973:401), it clearly does so. This was borne out in the next version of the model (Gibson and Nolan, 1974). This paper translated the descriptive model of the 1973 paper into a prescriptive tool to aid managers in dealing with computing growth. The model was used to explain growth patterns and to predict future growth within the context of changes in intra- and extra-organizational variables such as the emergence of new technology and increased organizational sophistication in computing use (Gibson and Nolan, 1974:77). The four stages from the 1973 model were presented anew, with some changes in their names, and were discussed in terms of the management challenges each stage poses. The most important change in this new formulation of the stages was the claim that the fourth stage, formerly called Integration, was actually a state of Maturity in use of computing. In this stage, the manager of the computing enterprize must balance the need for maintaining stability in computing use against the need to respond flexibly to new opportunities brought by changes in technology.

At the conclusion of the 1974 article, Gibson and Nolan revised the 1973 observation, and claimed that some organizations were already in Stage IV. More importantly, they stated specifically that the S-curve from which the changes were identified is driven primarily by changes in computing technology (p.88). They claimed that most changes to that point arose from advancements in hardware, but that future changes would come from advances in software, particularly data base management systems. Such changes were predicted to initiate new S-curves, and the same integrative problems present in the earlier four stages would underlie the future S-curves. Thus, technological change was established as the model's basic causal agent, and management reactions to those changes were established as the effects of that cause. Although not noted by Gibson and Nolan, this formulation posits Maturity as an equilibrium state in which computing growth is brought under control by appropriate management actions, and that would persist until new technological changes upset the equilibrium.

The 1977 Version

Nolan subsequently used the stage model in a study of the effectiveness of chargeout policies in eighteen firms (Nolan, 1977). In this study, the model was used to describe the firms in terms of their relative positions on the growth continuum. Although no data are presented to support the claim, Nolan states that the budget growth curve was used to develop an initial stage profile of the companies (Nolan, 1977:30). The detailed data that are presented suggest that the factoring of the firms by stage was accomplished primarily by comparing variables in individual firms to the variables assumed to be associated with each stage as outlined in earier versions of the model. Four variables were used in this analysis: the state of the firms's applications portfolio (eg., what computing is being used for); the nature of the DP organization within the firm; the characteristics of management planning and control for computing in the firm; and the level and character of "user awareness" in their use of computing (p.22).

Three important changes appeared in the 1977 version of the model. First, management responses for dealing with computing were dichotomized according to Cyert and March's (1956) concept of "control" and "slack." A control environment was characterized by the presence of elaborate management systems to ensure efficiency of computing use (eg., planning, budgeting, performance reviews, chargeout). A slack environment was characterized by a lack of such controls and a willingness of top management to spend more on computing use than is strictly required to do the jobs needed. A control environment would nurture efficiency but constrain innovation; a slack environment would nurture innovation but allow inefficiencies.

A second major change in this formulation of the model was the claim that the S-curve of computing budget changes also represents the organization's "learning curve" in the quest to control computing effectively (p.20). This claim, adopted from the work of Estes (1950) and Jordan (1965), was the turning point in the clarification of Nolan's model as a learning model: change in technology upsets organizational equilibrium; increased knowledge on the part of organizational actors reestablishes equilibrium [3].

Most of the remainder of the 1977 book deals with the establishment and use of chargeout systems and steering committees as control tools, and two models of the evolution of such tools are presented (pages 60 and 128). However, a third basic change in the stage model was presented at the end of the book (pages 153-160). Here Nolan claimed that a basic shift was underway in the orientation of management toward the control of computing. Control was shifting away from its focus on management of computing as a resource to management of organizational data as a resource. Nolan predicted that this shift would be enabled by the advent of the then-new technology of data base management systems, and that this shift would initiate two new stages in the model, following Integration (IV). (See points D and E in Figure 1.) He called the final stage Maturity. This new fifth stage was not named in the 1977 book, nor were its implications for the model discussed.

The addition of the new stages is important for understanding the development of the model. First, it fulfilled the prophecy of Gibson and Nolan (1974) that changes in technology, especially in data base management, would spur changes in the growth rate of computing. In this way the model was pushed beyond its descriptive role to a clearly predictive one. Second, addition of the new stage reinforced the development of the model as a learning model in which disruptions brought by technical change can be overcome through organizational learning resulting in the adoption of management policies to integrate the technology with the goals of the organization. This integration would result, in turn, in the equilibrium state of Maturity. The fact that the previously predicted state of Integration (Maturity) was either not achieved or was short-lived was not explored in this new version.

The 1979 Version

The last formulation of the model in the open literature was Nolan (1979). The ideas presented tentatively in the 1977 book were described in detail in this final article. The article began with the recognition that a prediction made by the earlier articles (1973 and 1974) did not come to pass: instead of leveling off as predicted, computing cost continued to grow rapidly. This failure was said to result from changes in both the external and internal environment of organizations occurring after the previous articles were written. The external changes were the appearance of new technologies and the knowledge of how to use them. Internal changes arose from the acquisition of experience, resulting in internal knowledge. Nolan still used the basic model, but expanded it to include the six stages discussed at the end of the 1977 book. His faith in this expanded model was based on additional studies made after the early model was developed (studies in 35 companies and a "large number" of IBM customers and other organizations; Nolan, 1979:116), although no data or references to data from these studies were presented.

The 1979 model formalized the "control" and "slack" concept of the 1977 book, and reanalyzed the four stages of the 1973 model in light of this concept. The two new stages were included (see Figure 2), and the whole model articulated anew: In Stage I few applications are installed, control is lax, and planning is almost nonexistent. In Stage II development is encouraged (ie., greater slack) but lack of planning results in systems of poor design quality. In Stage III the problems from bad design and rising costs create difficulties for users and management, so control becomes tighter. Users almost give up on getting what they want, but with the advent of data communications and user terminals they relax and become tolerant of rising costs they pay through the chargeout system. Top management has begun to rethink the management of computing in terms of data resources rather than computer resources. The organization then enters Stage IV, in which costs continue to rise rapidly as computing use increases [4]. Data base systems are brought in, which helps the move toward data resource management. In Stage V the focus of computing management turns completely to Data Administration, in which control of computing resources is tight but slack is maintained in development of systems that bring high added value. Stage VI, Maturity, is achieved when the applications portfolio is "complete" (how completion is recognized is not specified), and its "structure 'mirrors' the organization and the information flows in the company" (Nolan, 1979:120).

The 1979 version of the model retained many features of the earlier models. The budget curve was still used as the primary indicator of change, although this measure was modified to be the ratio of computing budget growth to sales growth. Changes in technology still served as fundamental drivers of changes in the stages. An end state (Maturity) was still predicted wherein costs rise slowly and benefits rise more rapidly. But the new version of the model differed from the earlier versions in important ways. First, the learning mechanism was fully incoporated. Change was said to be driven by technology, but modulated through internal adoption and application of external and internal knowledge. Second, the 1979 model claimed that a basic shift in organizational goals regarding computing management was taking place, from a focus on management of the computer resource to the management of organizational data resources. Finally, the 1979 model moved beyond the limits of its earlier versions, and was described as a tool for evaluating computing in individual firms. In closing the 1979 article, Nolan made the remarkable claim that "there is now a generic and empirically supported theory of the evolution of the DP activity -- the stage theory" (Nolan, 1979:125).

EVALUATION OF NOLAN'S MODEL

Basic Assumptions of the Model

Nolan's model rests on a number of important claims and assumptions that invite scrutiny. In this section we will assess these claims and assumptions in terms of their empirical validity and their plausibility.

1. Empirical Foundations. We have problems with some central empirical assumptions that form the foundation of the model. First, we question the initial hypothesis of the model: that change in budgets for computing can serve as a surrogate for such important and different variables as organizational environment, managerial strategies for growth of computing, and the organization's learning curve in dealing with computing. Is it reasonable to assume that a single variable serves as a suitable surrogate for so much? We think not. It is logically possible that this one variable tracks the changes in others, but it seems unlikely and Nolan does not provide any explanation of the probable linkages that would make the claim plausible [5]. Beyond this, we have problems with the derivation of such a complex set of stages from the turning points in the curve tracing budget changes (see Figure 1). Finally, there is little evidence in any of the versions of the model to suggest that budgets do follow this curve. Even assuming that Nolan's budgetary data for all the firms he investigated yield S-curves in conformance with his claims (the data presented are not sufficient to tell), there is evidence that many organizations' computing budgets do not show such behavior. For example, Lucas and Sutton's (1977) study of computing budgets in California local governments showed that growth in

computing expenditures tended to be linear rather than curvilinear (a phenomenon noticed by Nolan in the 1979 paper), and that more powerful explanators than Nolan's stage theory would account for this pattern.

This does not destroy Nolan's initial empirical assumption; it merely weakens its generalizability. We cannot test directly the correspondence between budget growth and changes in other variables without data on the firms he investigated. Nevertheless, the ideas embodied in the model can be validated empirically through tests of its predictions. Here again problems appear. The most obvious is one Nolan himself acknowledges: the failure of the slow-growth stage of Integration (Maturity in the 1974 paper) to appear according to prediction. Nolan explains this failure by extending the model to incorporate major contextual changes, in particular the shift in organizational emphasis to management of data resources and the emergence of data base management technology. But this is merely a rewrite of the premises to accommodate a change in the conclusions. If post-hoc analyses reveal flaws in the basic assumptions of the model, the predictive power of the model must be questioned. Nevertheless, the model in its later versions is used to make predictions. For example, in the 1979 version (p.121) Nolan predicts that the major new growth in computing budgets resulting from adoption of Data Administration will decline as adoption becomes complete in 2-5 years (from 1979 this means 1981-84). Whether this will happen remains to be seen.

Two recent empirical studies also raised questions about the soundness of the model's predictions. One was Goldstein and McCririk's 1981 study of 273 organizations that tested the model's prediction that Data Administration would be more formalized in "mature" data processing departments. The study failed to confirm the model's prediction. The other was our own study of computing in 56 cities in ten countries (Kraemer and King, 1981). While not specifically designed to test the Nolan model, this study collected extensive data on the variables that the budget curve in Nolan's model is said to capture (eg. environmental variables, computing management policies, outcomes of computing use). Our data permitted the grouping of the organizations into categories according to their "stage" of computing development. But the study also found that those organizations using the more "mature" policies for computing management as articulated by the Nolan model also were suffering from the highest levels of problems with computing. Either these organizations had adopted mature policies for computing management but had not refined them sufficiently to make them work right; or the whole concept of organizational learning in dealing with computing is somewhat optimistic [6]. In any case, the primary claims of empirical support for the predictions of the model come from Nolan himself, and have not been corroborated by others.

These problems with the empirical bases of Nolan's model restrict its acceptance as a validated theory in the scientific sense of that term. The question remains, is the theory intuitively powerful and practically useful? By examining the remaining assumptions behind the model listed above we see that some serious problems remain.

2. Technological Change. The model holds that technological change is the primary driving force behind the growth of computing through the stages (Gibson and Nolan, 1974:88; Nolan, 1977:20; Nolan, 1979:116). This probably overstates the dominance of this variable. Technological change certainly plays a role in the complex of factors that drive change, but there are additional factors that should be considered. Most important are the "demand-side" factors that create a ripe environment for technological changes to be considered and adopted [7]. At least three such forces seem appropriate for consideration. One is the "institutionalized demand" created by the extant presence of computing in organizations (Kling and Scacchi, 1982; Scacchi, 1981). Once routinized computing applications must be maintained and upgraded over time. Such changes add to the costs of computing, and to the need for even further changes (eg. hardware upgrades, more disk storage), irrespective of changes in technology. Another is demand among users for computer services arising from powerful but often overlooked aspects of computing as a politicical resource (Danziger, Dutton, Kling and Kraemer, 1982; King, 1983; Kraemer, 1980; Markus, 1981). Computing brings capabilities that are more desirable for some users than for others, and the use of computing provides departments with opportunities to justify additional capital, personnel and space demands. Finally, computing is appealing to many people on purely affective grounds as an entertaining and status-increasing technology (King, 1983). These demand-pull drivers of change can and often do take precedence over the supply-push factors of technological change.

3. Clarity of Organizational Goals. The model assumes that there are clear-cut organizational goals to be realized through application of the technology (Nolan, 1973:399; Gibson and Nolan, 1974:88; Nolan, 1977:3; Nolan, 1979:116). This assumption might apply to some organizations, but not to all, and possibly not to many. The question of whether organizational goals are uniform and consistent guides for the behavior of organizational actors, as opposed to dynamic and changing targets that result from competition and conflict among organizational actors, has received considerable attention in the literature on computing (Keen and Scott Morton, 1978; Kling, 1980; Kling and Scacchi, 1982; Danziger, Dutton, Kling and Kraemer, 1982; King, 1983; Pfeffer, 1978). This research suggests that the setting and maintenance of organizational goals is a dynamic process in which internal disagreements on strategy are only resolved temporarily through goal-clarifying processes, and that organizational norms that result are often temporary [8]. If the organizational goals for the application of computing are themselves undergoing change, there can be no lasting consensus on how "best" to manage computing activity, and no reasonable expectation that management will know what it is searching for in its effort to master the technology. Very general goals of the organization might be agreed on (eg., making a profit, organizational survival, sustained growth), but the linkage between use of computing and the achievement of these broad goals requires specification of much more detailed sub-goals directed specifically at the application of the technology to particular tasks and needs. Given the array of possible demand-pull factors on the growth of computing mentioned above, agreement on sub-goals cannot be assumed a priori, and that different goals of organizational actors

will have unitary correspondence with agreed-on organizational goals cannot be assumed at all.

4. Knowledge. The model assumes that increased external and internal knowledge will eventually lead to effective and efficient control over computing (Nolan, 1977:20; Nolan, 1979:116). This assumption poses difficulties because it implies the further assumption that the "right" knowledge is available and that organizational actors will acquire and act appropriately on this knowledge. External knowledge, which in the Nolan model enters the organization in the form of new technologies and information about how to exploit them, varies greatly in its utility. There are many competing theories about how best to exploit computing, and there are no proven tests by which a manager can tell which theories are correct and appropriate for the organization in question. Internal knowledge, which is based on organizational experience, also varies greatly from from one organization to the next. Some organizations have been successful in routinizing sophisticated computing applications, others have not. According to Nolan's model, successful organizations are those that have learned how to cope with the technology, while unsuccessful organizations have not. But what accounts for these differences in learning? The model does not answer this question. The processes by which knowledge is brought to bear on problems are not explained in the model, and there is no specificiation for how the appropriate policies leading to Integration, Data Administration, and Maturity are found and applied.

5. Control vs Slack. The model assumes that the task of effective management of computing is to strike a balance between "control" and "slack" (Nolan, 1977:22; Nolan, 1979:116). This implies that top management, which has the prerogative to implement "control" or "slack" policies, can know when either course is appropriate for each of the policies they promulgate. Policies must be chosen from someplace on the "control" to "slack" continuum, but from where should they be chosen in any given instance? If policies are to be proactive, management must be able to anticipate when policies embodying greater control or greater slack will achieve desired ends. This implies that managers will know which way their organization is headed in its use of computing. In fact, most policies for computing management are probably reactive, developed in response to problems experienced with computing. Control and slack might be good general descriptors of the characteristics of policies managers can follow, but simply categorizing policies this way does not indicate what policies managers should follow.

6. Continuitous Change. The model assumes that change in organizational information systems is a continuitous process [9]. Our observations of the processes of change in organizations lead us to doubt this assumption. The S-curve implies continuitous change, but does not accommodate the cyclical or recursive behaviors so often encountered in the development and refinement of organizational policies. As noted by Moore (1967:259), most organizations exhibit cyclical behavior in resolving basic policy dilemas such as whether to centralize or decentralize functions. The adoption of a function such as the smooth S-curve might be appropriate for characterizing the the

ideal theoretical behavior of a single organization, or for summarizing the aggregate behaviors of a populations of organizations, but it does not fit well the often erratic behavior exhibited by individual organizations.

These problems with Nolan's model do not disprove the model's assertions. However, they do raise important questions about the empirical validity of the model and its utility for describing the process of change in specific organizations. In the next section we will assess the model's performance as an evolution theory of the growth of computing across organizations.

The Model as an Evolution Theory

Nolan describes his model as a theory of the evolution of the DP activity in organizations (Nolan, 1979:125). In this section we evaluate the model in the context of evolution theories in the social sciences to determine the extent to which this discription is correct [10].

In its simplest conception, "evolution" refers to any succession of changes that affect an entity (eg., a species, an industry, a society). The terms evolution and evolutionary are used interchangably and imprecisely much of the time. A distinction must be made between models that characterize successions of change by the direction the change is taking, and those that characterize such successions of change by their mechanisms (van Parijs, 1981:51). Models that describe change in terms of direction can be called "evolutionist" models, and are distinct from "evolutionary" models that describe change in terms of mechanisms.

The evolutionist perspective assesses history as a developmental, progressive and directional set of changes that increase in their complexity or perfection with the passage of time. Such theories embody a clear concept of the direction of change and the destination of change. Evolutionist models explain the logic of development, typically in the form of stages that follow one another, and in which each stage is a precursor for the next one. More elaborate evolutionist theories extend to the description of the dynamics of development, in which successions of stages correspond to a path along which entities are inexorably compelled toward their appointed "end state."

Evolutionary models, by contrast, are agnostic about either the direction of change or the likely end state to which change is headed. Evolutionary models focus on the mechanisms by which changes occur and new features of entities come into being. Evolutionary mechanisms are mechanisms of local optimization in which features of an entity change (either through genetic mutation or adoption of new behaviors), and the new features are preferable to old features in aiding survival of the entity or improving its chances of satisfaction. If the new state is "adequate" for the entity (that is, it can survive and reproduce, or it is satisfied), current features are stabilized, resulting in a new state of equilibrium. The consequences of "selections" made by these mechanisms feed back and influence the process of change toward a new state of locally optimized equilibrium.

An initial reading of the model, particularly in its earlier versions, suggests that it is an evolutionist theory. The persistence of change in information systems is noted, and the model attempts to explain the course of change in terms of its direction (growth) and its "end state" (Integration or Maturity). This formulation, as with many evolutionist theories, bears a striking resemblance to "life cycle" models that parallel the process of change in living organisms (birth, growth, maturation), although there is no expectation of a final state of demise (death). The model stops at maturity.

The other evolutionist characteristic of the model is its focus on the logic of what happens rather than on the mechanisms by which particular changes take place. Although discussions of the model embody predictions about further changes, these predictions are based mainly on the trends in past change. The model concentrates more on these trends in change than on the persistent features of the entities (organizations that use information systems) and why they are there. The explanations of the presence of features are functionalist in that they account for the purpose of the features, but generally within a rationalistic framework in which organizational actors learn what to do and then do it. While the primary incentive for change comes from without in the form of changes in technology and external knowledge, the reaction to this change is purposeful on the part of the organization's leadership. As with many of the better known theories of social evolution, especially those arising from the philosophy of Hegel's dialectics, a constant tension between change in environment and organizational reaction to change is the primary structural feature of the model [11]. The evolutionistic twist here, in these social theories and in Nolan's model, is the belief that an end state is somehow eventually achieved.

To the extent that Nolan's model is an evolutionist theory, it exhibits the same strengths and weaknesses of other evolutionist theories. The primary strength of such models is their attention to the logic of past development, which can be assessed empirically as long as correct historical accounts of change are available. In this sense the Nolan model does ring true, as many of its characterizations of the history of organizational information systems are insightful. In the end, the predictions made using such models might very well turn out to be correct. If a model truly captures the basic driving forces behind change and accurately specifies the relationships between these forces, and assuming that larger contextual features of the "change space" do not themselves change, there is nothing to prevent evolutionist theories from being powerful predictors. However, the primary weaknesses of evolutionist theories rest precisely in the generality of their perceptions of reality and the resulting difficulty in assessing their factual correctness. Such theories are concerned with the broad picture of change, and not with the actual experiences of change in individual cases. The lack of mechanistic explanation in these theories makes them difficult to test empirically at the level of individual instances of change. Rather, they can be empirically tested only by examining the correctness of their historical accounts or by waiting to see whether the predictions made using them turn out to be correct. Evolutionist theories are therefore useful organizing frameworks that might prove to have been insightful and correct once enough time has passed to see whether their predictions have come to pass. But they do not explain why changes happen the way the way they do. This limits their utility in explaining changes or predicting the future of change in specific instances.

There are elements of evolutionary explanation in the Nolan model, too, and these are worth noting. Gibson and Nolan (1974) first suggest the possibility that the "end state" of maturity is not in fact an end state, but rather an equilibrium state. This allows an interpretation of the model in terms of locally optimized equilibrium states common to evolutionary theories. Under this construction, there are forces of environmental change (eg., technological change, new external knowledge) that affect the current state of an entity (the organization) that is capable of recognizing that the changes have altered its chances of satisfaction under the current state. The entity is also capable of recognizing (through internal learning) that local alternative states are comparatively attractive. A mechanism used in evolutionary explanations in social sciences called "reinforcement" causes the entity to alter its persistent features (behaviors) to correspond to those alternatives [12]. If adoption of the alternative features provides sufficient improvement in satisfaction to accommodate the environmental change, and no other locally available states appear more attractive, the entity has evolved to a new state of locally optimal equilibrium.

In this interpretation, the selection choices available to the entity in its search for satisfaction are limited to policy options that range from "slack" to "control" along one dimension. There can be a number of different policies adopted, and each policy falls somewhere along the slack/control continuum. The earlier versions of the model portrayed policy as a monolithic variable: the sought-after state was a simple balance between slack and control (although these terms were not used). In later versions, the model is modified to accept greater control in some variables and greater slack in others. The preferred state would result from balance between slack and control for each major policy variable.

In an effort to improve its recognition of what policies are appropriate, the organization evolves toward a state of improved planning; that is, an intensified effort to anticipate the future and develop appropriate controls for the present to improve chances of future satisfaction. But in this the Nolan model departs somewhat from a truly evolutionary theory. Planning implies the anticipation of consequences, and in its ultimate formulation, the presence of an omniscient actor capable of seeing the future. The presence of such an omniscient actor would remove all aspects of evolutionary explanation and substitute instead a purely "actional" explanation [13]. Since we cannot assume omniscience, the goal of planning is less to provide foresight than to anticipate a bounded set of likely characteristics of the future, and assess options that might improve satisfaction under each anticipated case. The reinforcement mechanism in this case continues to operate through consequence-feedback, and planning remains limited to educated guesswork [15].

CONCLUSION

On close examination, the Nolan model reveals some shortcomings. The empirical bases of the model are questionable, and some evidence is available that they are factually mistaken. Many of the other structural assumptions of the model are too simplistic to be useful, or are simply implausible. As noted above, the criticisms of the model we provide do not eliminate it as a contender in larger effort to figure out how computing systems evolve in organizations. They simply suggest that the model is flawed in important ways, and that much more vigorous empirical testing might discredit it altogether.

Nevertheless, the Nolan model has had a powerful influence on the information systems field. The popularity of the model probably comes from its bold approach to dealing with a phenomenon of great complexity in a straightforward and clever manner. There are many aspects of the model that ring true to researchers and practitioners alike. It attempts to capture the larger organizational context within which computing occurs, and to draw relationships between the various components in this context. It also integrates the insightful contributions of other research, particularly in its characterization of the accommodation of computing as an organizational learning process, and in specifying the choice range for selecting policies between "slack" and "control" options. Regardless of the validity of the model itself, much of the analysis that appears in the articles that develop it is highly useful in describing the kinds of changes that do happen in computing environments and speculating about why they happen. The model has earned a place in the tradition of research in information systems for its longitudinal perspective on computing use, and its incorporation of the larger milieu within which computing use takes place.

NOTES

1. The work reported in this paper has been supported by grants from the National Science Foundation. The opinions presented here are the authors' and should not be ascribed to the National Science Foundation. Authors' names are listed in random order.

2. We use the title "Nolan Model" for convenience. Nolan himself described the origin of the model and the role others played in it in Nolan (1977:21).

3. Gibson and Nolan (1974) suggest obliquely that the stage model is a learning model, but the claim is not made explicit until the 1977 version.

4. A curious puzzle is evident here. A major purpose of chargeout policies was to impose market-like constraints on users of computing that would help attenuate uncontrolled growth. Did chargeout fail? The model does not say.

5. There is an implicit danger of circularity in this kind of model. The shape of the cost growth curve is due in large part to the influences of the major variables of environment, technology, etc. Yet the curve is used to demonstrate what changes in these variables take place. The model is too loosely specified to see whether this danger is serious. It could be that the behavior of the cost curve is not significantly caused by the changes in these other variables, but merely correlates with them. In this case there would be no circularity, but the claim that the cost curve does capture the behavior of the other variable would be correspondingly weaker without empirical evidence to back it up (cf., van Paris, 1981:27-30, 112-114).

6. As with the Lucas and Sutton (1977) study, our research was conducted in local governments. An argument can be made that our findings are entirely explained by differences between corporations of the kind Nolan studied, the counties Lucas and Sutton studied, and the cities we studied. We doubt it, however.

7. The concept of "supply-push" and "demand-pull" in the process of innovation diffusion is extensively explored in Tornatzky, et al (1980).

8. Among the versions of the Nolan model, Gibson and Nolan (1974) and Nolan (1977) come closest to acknowledging conflicts in goal setting. In neither case is such conflict explored as important for the assumptions of the model.

9. Continuitous change means that change occurs in a logical gradation of steps within a single series, and is an assumption common to many theories of social evolution (Nisbet, 1969).

10. This brief discussion of evolution concepts in the social sciences is informed by several sources, particularly van Parijs (1981, especially chapter 2), Moore (1967) and Nisbet (1969).

11. See Nisbet (1969, chapter 5) for an extensive discussion of this matter.

12. A thorough discussion of reinforcement as an evolutionary mechanism, and particularly its dissimilarity to the more commonly cited natural selection mechanism, is found in van Parijs (1981, chapter 4). The natural selection mechanism has been applied to the analysis of computing growth by Swanson (1982).

13. The actional view refers to the deliberate actions of entities given correct anticipation of the consequences of action (van Parijs, 1981:18-20, 51-53).

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