COMPLEXITY AND ORGANIZATIONS

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Contents

Summary

Nonlinear dynamical systems theory has contributed to the understanding of individual, group and organizational processes. The most frequently investigated individual processes pertain to the effects of stress, motivation, and work performance; catastrophe models are the most prevalent dynamics in those applications. Occupational accidents have also been studied as catastrophe dynamics at both the individual and group level of aggregation.

Other group dynamical processes involve idea production in creative problem-solving groups, coordination within work teams, leadership emergence, and the development of virtual societies. Creative problem-solving group behaviors involve self-organizations from the vantage points of idea elements and the social interactions that occur. There are two types of conversational output, one of which is a general information flow, and the other consists of especially creative contributions. The combination of outputs follows an umbilic catastrophe process over time.

Other analyses of group dynamics involve the calculation of Lyapunov exponents and dimensions from behavioral time-series for group coordination, creative problem-solving output, and the bandwagon dynamics that characterize the development of virtual societies.

In those applications, the Lyapunov values were calculated through nonlinear regression and provided tests for the presence of chaos, fixed point attractors, and bifurcation dynamics that are shared with population dynamics models.

Self-organization dynamics are apparent in the intersection-type coordination behaviors and in leadership emergence. Self-organization in the former case is similar to the flocking of birds or herds. In the latter case it is more similar to a rugged landscape dynamic. The emergence of primary and secondary leaders took the form of a swallowtail catastrophe model.

The organizational processes include work behavior in hierarchies, a general model for organizational change and development, and strategic management. A variety of dynamics were involved in that group of applications.

1. Introduction

Nonlinear dynamical systems theory contributes to organization science in three fundamental ways. First, it provides a stock of metaphors that can be used to solve practical problems. Second, it provides a theoretical foundation for the continued advancement of the scientific study of organizations; it provides propositions that are explicitly testable and objectively evaluated.

The third major potential contribution of nonlinear dynamics is in the management of organizations. Knowledge gained from theoretical and empirical studies often suggests new approaches to the management of uncertainties and decision making.

This chapter summarizes the current state of progress of nonlinear dynamical systems in the development of relevant theory organization science through empirical study. Familiarity with the dynamical concepts of attractors, bifurcations, the logistic map, self-organization, and catastrophe models is necessarily assumed.

The empirical analysis of the dynamics of organizational phenomena has usually required time series of interesting behaviors, phase portraits, and statistical assessment using polynomial and exponential structural equations. In many cases it has been possible to determine the relative merits of a nonlinear dynamical explanation for a phenomenon and compare it to conventional explanations.

In those cases, the nonlinear dynamical explanations have been found to be more accurate than conventional explanations by a margin of 2:1, based on variance accounted for in dependent measures (or order parameters) that were critical to the hypotheses in some way.

Applications of nonlinear dynamics have addressed phenomena whereby the individual interacts with the organization, phenomena that occur within groups, and phenomena that involve the organization as a whole. Topics in the individual category involve work motivation, stress and work performance, and accident analysis and prevention.

Topics in the group category involve creative problem-solving groups, task coordination among group members, and the emergence of leadership. Topics in the organizational category involve work performance in hierarchies, a general model of organizational change, and strategic management. Some further expansion of nonlinear dynamics to the management of uncertainty appears in a different chapter elsewhere in this volume.

2. Individuals and Organizations

The applications in this category take the form of catastrophe models for various types of workforce dynamics. Their principal themes fall into four major groups: models for work performance under conditions of stress, motivation, accidents and risk analysis, and creativity.

The data used in the validation studies included analyses of industrial production and casualty records, surveys completed by industrial work groups, records of students' academic performance and standardized test scores, and transcripts of verbal production from problem-solving groups who worked together over the internet or in real time. The essential points of the model groups are discussed below.

2.1. Performance Under Conditions of Stress

There are three conceptual models for work performance under stress: the diathesis-stress model, buckling under load, and fatigue. A diathesis-stress model is one where the health or performance of the human subjects is susceptible to destabilization from an interaction between an inherent biological fragility and an environmental assault.

The primary example is the case of rotating shift workers. Work performed by day and night shifts was more likely to be performed efficiently than comparable work performed on the afternoon-early evening shift; there was a limit cycle operating here as the diathesis element.

Some job specifications placed greater cognitive demands on the workers, thus exaggerating the natural performance variation associated with shift work (bifurcation). Of additional importance, some management and leadership improvements were taking place during the period when the data were collected.

The nature of this effect induced a distortion of the cyclical performance trend from an attractor at the low performance sheet of the cusp surface to the attractor at the upper performance sheet of the cusp (asymmetry).

The buckling model for work performance is closely analogous to Euler buckling for an elastic beam. If increased weight is applied to a highly elastic beam, buckling would be observed, but the beam would not snap. The opposite is the case with a rigid material.

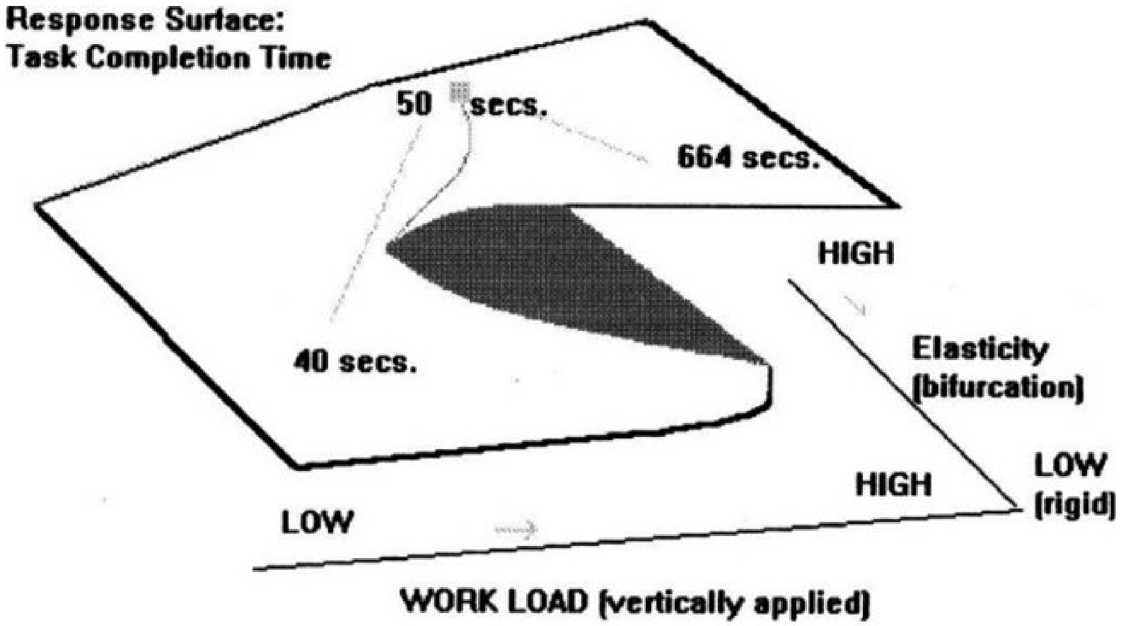

Figure 1: Catastrophe model for Euler buckling stress and its effect on work time

In work load dynamics, work load would function as the asymmetry parameter as it did in the materials case. The bifurcation factor would consist of human attributes that make a person more flexible to increased load. Those that "snap" are those that are observed suddenly to lose productivity when a greater load has been applied. In the empirical illustration, steel workers were timed as they completed a wheelbarrow obstacle course, with loads increasing from 45.5 to 136.6 kg. The more flexible workers, who demonstrated only small performance fluctuations tended to be male, taller, and demonstrated good body balance on a test given in a different phase of the experimental procedures. The less flexible workers, whose work time increased substantially or who could not complete the task at all when load was increased, tended to be female, shorter, or demonstrated poor body balance.

Fatigue is a loss of work capacity over time, and is typically related to the amount of work a person does over a continuous time without a rest. Early twentieth century studies on work curves and fatigue had actually identified a cubic polynomial function for work curves that was closely akin to the cusp catastrophe.

The cusp catastrophe function was re-applied in the early 1980s in a study of physical fatigue among steel workers. Workers were measured on dynamometer arm strength before and after a two-hour period of simulated work of the types commonly performed by steel workers. There were cusp-catastrophic changes in arm strength such that some workers lost capacity while others gained.

Leg strength functioned as a compensation strength variable, and took the form of the asymmetry parameter in the model. The bifurcation effect was composed of sets of situational variables, one of the most important of which was the total amount of work performed by a person during the two-hour period. Similar cusp dynamics also characterized performance changes after extended periods of mental work.

2.2. Motivation

The butterfly catastrophe model of motivation in organizations draws together many of the previously-known dynamics affecting personnel selection and training, motivation, work performance, absenteeism, and turnover. The vantage points of several motivational theories are implicitly represented in the model. The butterfly catastrophe model consists of three stable states of performance and four control parameters. The four control parameters are ability (asymmetry), extrinsic motivation (bifurcation), intrinsic motivation (swallowtail), and a management climate that tolerates individual differences and encourages intrinsic motivation to dominate over extrinsic motivation (butterfly).

Although all parts of the model, including the butterfly structure itself, have been empirically verified, it should be noted that some practical applications of this model may involve only subsets of the butterfly dynamics. The full possible range of work behaviors may be more complex than what might be observed in specific work settings. For example, a cusp subset of the model has been used to study turnover among nurses as a function of organizational commitment and job tension. Additionally, variations of the motivational model were developed to explain prison riots and civil unrest. Personnel selection decisions can often be framed in terms of the lower two performance regions also.

The butterfly catastrophe model of motivation in organizations is shown in Figure 2. The response surface is a three-dimensional slice of a five-dimensional surface. The control parameters are labeled on the bifurcation set. The bifurcation set is a four-dimensional shadow of the five-dimensional surface; a two-dimensional slice is shown here. Unimodal and bimodal regions of the response surface are marked.

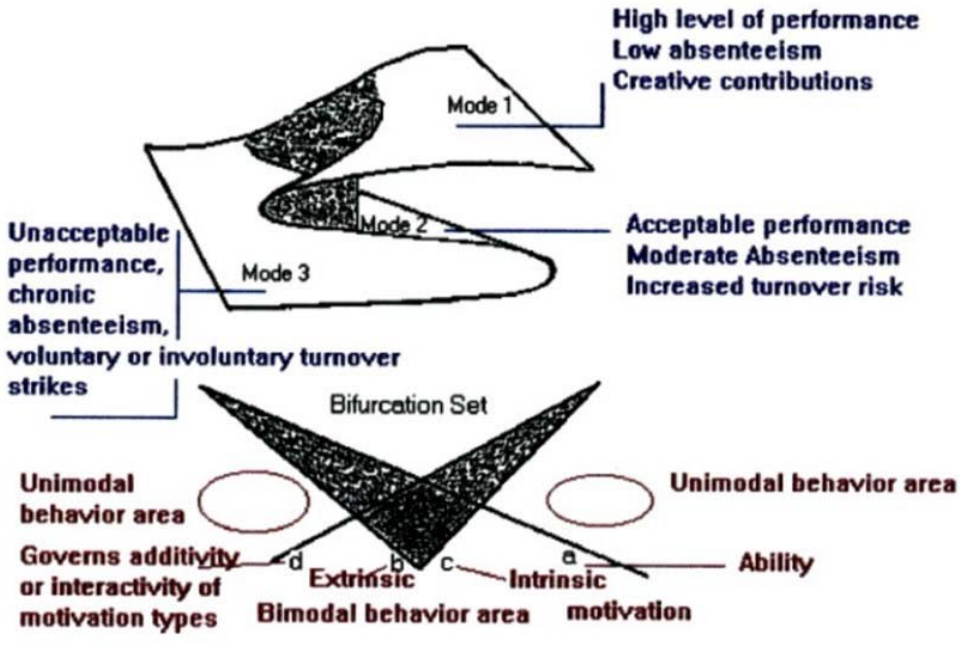

Figure 2: Butterfly catastrophe model of motivation in organizations

2.3. Accidents and Risk Analysis

The simple occupational accident can be characterized as a cusp catastrophe, particularly when collective accident rates are compared across situations. It is intrinsic to the theory that accidents are the result of a systemic process, and not the result of individuals' contributions only. The two stable outcomes states are high and low risk levels. The asymmetry parameter is the level of environmental hazard. The bifurcation factor acts as a triggering device, such that a high level of psychological load on the worker would have a hazardous impact, given that the environment was sufficiently dangerous. Psychological load involves several sources of physical and social stress, the effectiveness of management control policies, and the belief that accidents can be controlled.

Stress-related medical disorders can be substituted for accident rates in the foregoing model. Different combinations of load elements become salient for each specific type of illness, (such as a heart condition, kidney failure, carpal tunnel syndrome, insomnia, etc.), but the general model still holds. Underlying both the medical and accident versions is a contagion dynamic. The general workplace is viewed as a source of stress influences that can act on any one worker in the group. When one worker becomes a casualty, the anxiety and stress level for the entire group becomes elevated, which predisposes more workers to greater risk. A good management control policy, however, would reverse this process.

3. Group Processes

The group processes involve a variety of dynamical models. Creativity involves concepts of chaos and self-organization for idea generation, coupled dynamics during group discussion processes, and the mushroom (parabolic umbilic) catastrophe to describe two different types of information flow. Leadership emergence is the end result of a rugged landscape self-organizational process and a swallowtail catastrophe dynamic. Coordination is essentially a game-theoretical process.

In one of two applications studied, task coordination takes the form of an intersection game, which in turn has the dynamical character of a fixed-point attractor in most conditions, and a second chaotic process in others. In a different application, coordination takes the form of a bandwagon dynamic, which in turn is dynamically similar to a May-Oster population growth function.

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Biographical Sketch

Stephen J. Guastello is Professor of Psychology at Marquette University. He is widely published in the fields of complexity, psychology and organizations. He is the author of *Chaos, catastrophe, and human affairs: Applications of nonlinear dynamics to work,* (1995, Lawrence Erlbaum Associates) and the forthcoming *Managing Emergent Phenomena: Nonlinear dynamics in work organizations.* (Lawrence Erlbaum Associates). Dr. Guastello is also the editor-in-chief of the journal *Nonlinear Dynamics, Psychology, and Life Sciences***.** He has served as a consultant to numerous organizations providing expertise in the areas of personnel selection and retention, occupational accident analysis and prevention, and management development.