WORKING PAPER
ALFRED P. SLOAN SCHOOL OF MANAGEMENT

Evolution of a Sociotechnical System

A Model and Some Implications

By

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WP 1054-79 March 1979

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Abstract

A complex sociotechnical system is composed of many people and many types of equipment interacting together to perform some set of tasks. A model of the process of evolution of these systems is described, detailing the search, decision and implementation phases. Behavior in all stages and the ensuing evolution path are strongly influenced by present system properties, the decision process governing it and the quality of feedback. A system acts as a filter that prefers those changes which cause minimum disruption to its present state. Hence, radical disruptive change is usually championed only by new comers and young fluid organizations; whereas large mature systems would usually accept only incremental change often characterized by technology lag and very slow adaptation of structure. Coming papers will discuss various aspects of this process in greater detail.

Introduction

A complex sociotechnical system (1)(STS) is composed of many people and many inanimate systems interacting together to perform a set of tasks/missions. This definition encompasses a wide variety of systems i.e. production lines and plants, computerized business systems (air line reservations system), rail network, R & D groups, military formations (tank company, ground to air battery). More generally, a sociotechnical system (STS) may be as small as a small workshop with a few people or as large as a big societal system (sociotechnical macrosystem).

A complex STS is not created overnight or built in one piece. It evolves gradually through an intricate process involving both technological and social change. Thus, a real issue posed by complex sociotechnical systems to system theory is not how to design and optimize a large scale system from scratch, but rather how to understand, facilitate and perhaps improve the process of evolution.

Various authors have discussed factors influencing this process, each emphasizing particular factors: economic, organizational, technological, etc. Other authors have dealt with organizational tasks at various stages; search, decision, implementation. This paper attempts to present an overall aggregate model and overview of this process, trying to include most major stages and factors and their interaction. It deals specifically with the evolution of a single STS which has some form of central management.

Beginning with a description of a simplified model (sec. 2) later sections detail the influence of the present STS throughout the process (sec. 3), the search process and overall goals (sec. 4), the decision process (sec. 5), the implementation process (sec. 6) and finally a fuller and more detailed overall model combining all the parts (sec. 7). The implications of this model to the processes of evolution of various sociotechnical systems are described in sec. 8. These conclusions are supported by case studies in many fields.

In a specific case, the model could help in the analysis of the problems of change, locate the major barriers to further evolution and aid in designing a suitable change strategy.

2. Simplified Model of the Evolution Process

A simplified model of the evolution of a STS is shown in fig. 1. Opportunities and threats, perceived performance gaps and available resources, all activate the search and decision process (2). The intensity of search depends mostly on perceived performance gaps and on available resources. In the decision process various alternatives for action, including the status quo, are compared on a cost-benefit basis. Once a change decision is taken, it will usually require a considerable time for implementation, hopefully causing improved system performance. The quality of performance feedback plays a major role in the unfolding of this

Simplified System Evolution Process

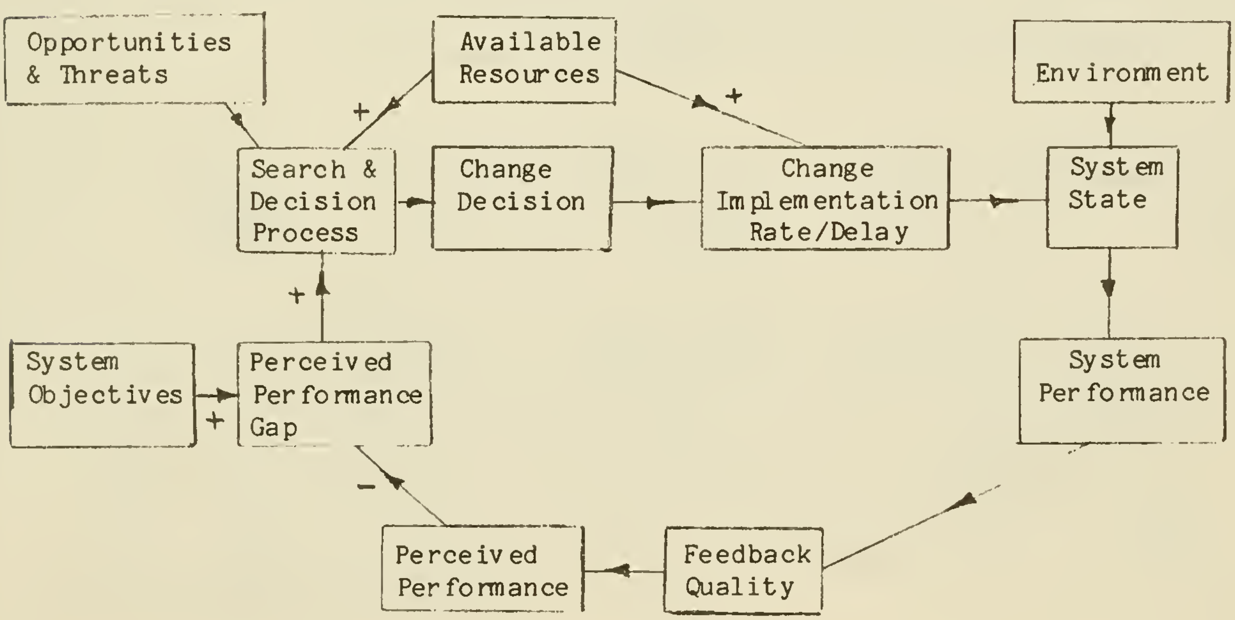


Figure 1

process. Lack of feedback (e.g. military systems in peace time), distorted and/or delayed feedback, feedback magnifying small implementation problems, these and other feedback aberrations lead to particular behavior.

This simplified picture omits the major role of the following factors in determining the process of evolution:

1. Present STS state.
2. The decision structure governing the STS.
3. The type of change.

3. STS State Influence

STS state is defined by the following attributes:

1. Values and objectives.
2. Structure: the set of roles and relationships among STS members.
3. Equipment and technological processes.
4. Personnel specific skills and training.

STS present state is due to past investment and efforts, that is sunk costs. A change in any attribute involves costs. For example, changes in structure, involving disruption of past roles and relationships, often

System Influence on Search, Decision & Implementation

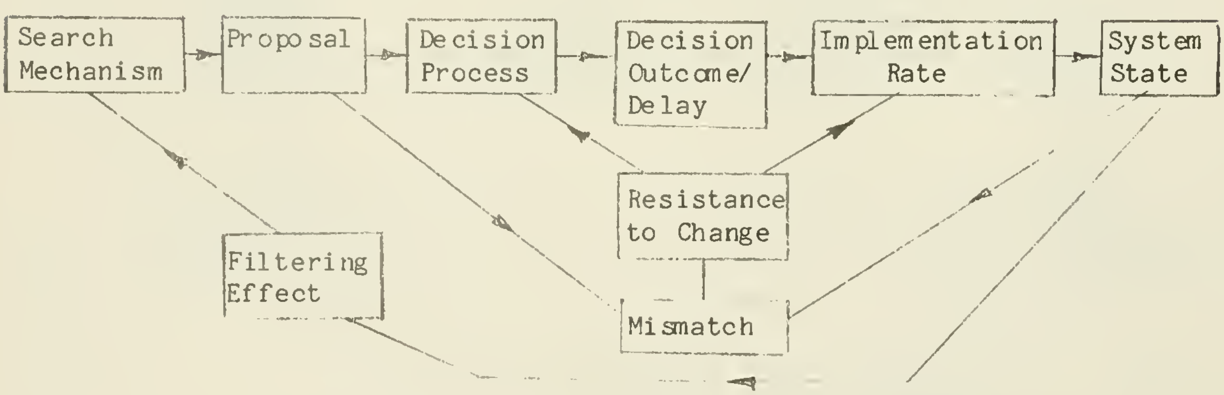


Figure 2

cause uncertainty, apprehension and resistance among members, making sometimes the social cost of change much bigger than the monetary cost of equipment changes. STS tends to resist costly changes, i.e. radical changes which may cause large disruption in its present state (3 pp. 34-40, 4). Hence, a (large) mismatch between the present state and that required by the (radical) change proposal will cause (large) resistance to change in both decision and implementation[1] (fig. 2).

Moreover, the search function is characterized by selective perception (5, pp. 150-155) confining the search mostly to present STS-matched opportunities. Thus, STS tends to act as a filter that considers and prefers those changes which cause minimum disruption to its present state (fig. 3).

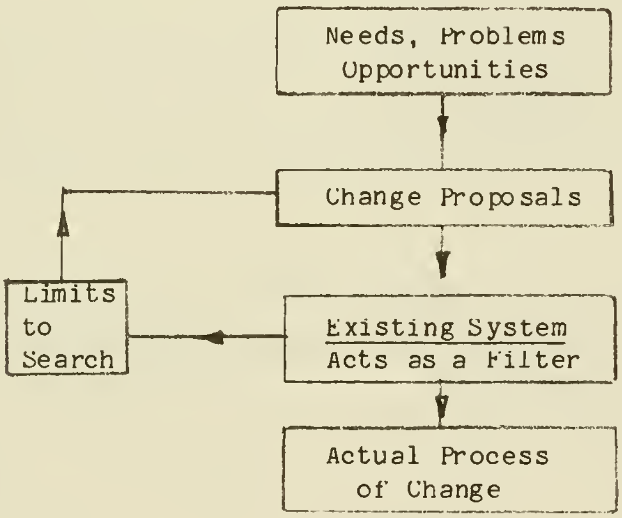


Figure 3

1 Estimates of system-proposal mismatch and the generated resistance to change due to attributes 1 and 2 are appearently difficult. However, in a specific case, one can estimate the magnitude of values and objectives change, the number and influence of people who cannot or will not accept these changes, the required indoctrination for other personnel etc. Analysis of new versus old structure will reveal how many people would suffer a major, minor or no change in role and relationships, what is their influence and what kind of resistance they can generate. Though these estimates look fuzzy. They are not worse than some cost estimates for new high-risk technological equipment.

System state affects also performance feedback as described in the following section.

4. <u>The Search Process and Overall System Goals (Fig. 4)</u>

Performance gaps may be caused by changes in the STS itself or by changes in its environment including competition of other systems. Search, however, is activated not by real performance gaps but by perceived performance gaps. These depend on feedback quality which depends not only on system type (e.g. military systems in peace time) but also on system state. Danger signals are not perceived or ignored all-together due to selective STS perception.

Search Process

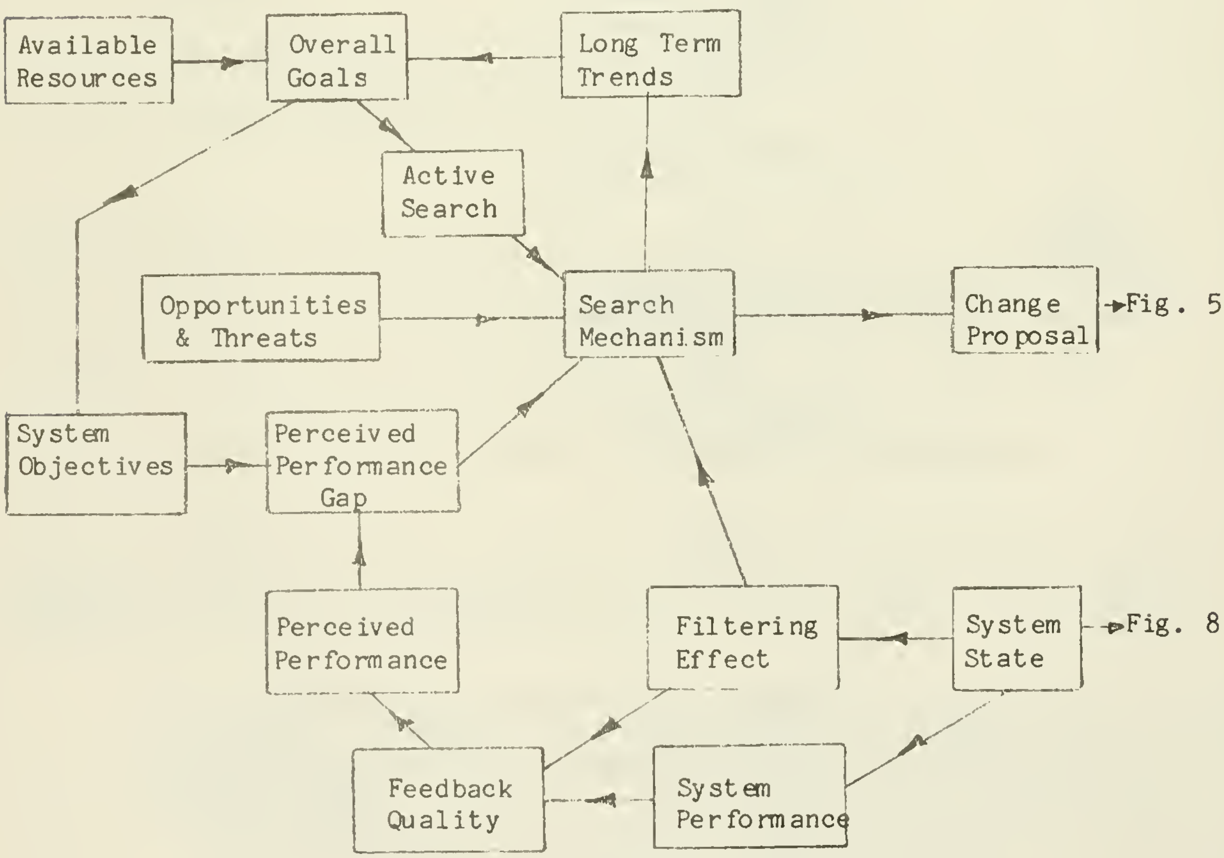


Figure 4

Normal search activated by perceived performance gaps will usually be limited to normal incremental change proposals (2) due to present STS state filtering effect (unless the search mechanism is external to the system, sec. 3). Only when the performance gaps become large and really threatening will the search mechanism change and start to look for radical solutions.

This can be obviated by the existence of an active search policy regarding the level and type of search as well as suitable search mechanisms (R & D laboratory, independent market research, new-ventures organization) encouraging

1. Search for new opportunities even when no performance gaps are perceived.

2. Search for radical change opportunities.

Active search policy depends on overall system goals. Availability of uncommitted resources will encourage active search for new uses for these resources.

Overall system goals usually change very slowly responding to changes in the environment as perceived by the search function. Goals' change causes reformulation of system objectives and search of means to achieve them. However, system goals are also affected by perceived performance. Persistent success or failure in achieving certain objectives will lead, after some time, to reevaluation of system goals and changes in objectives.

5. The Decision Process

The decision process may vary all the way from a rational analytic-synoptic one to an almost purely political bargaining process depending on the following factors:

1. Decision Structure.
2. Change Proposal Properties.
3. STS Present State (sec. 3).

These are considerable differences in decision structures between various types of organizations (e.g. business firms, government agencies, university departments). Also the decision structure governing a specific system may be, partly or even completely, outside it (i.e. the system has little autonomy)

Change proposal properties include:

1. Size (Cost) and complexity.
2. Uncertainties in equipment technology, system structure and external variables affecting change results.
3. Influence on system present state.

A specific change proposal, which is normal to one STS, i.e. requiring little change is its present state may be quite radical with respect to another STS requiring large change in its state and threatening severe disruption.

An overall diagram of the decision process is shown in Figure 5. The "decision collective" includes all people involved in a specific decision, formally or informally, inside as well as outside the formal boundaries of the system. Hence it depends on the decision structure, system state, and the specific change proposal considered. A large change proposal will involve a larger part of the STS hence increasing the decision collective. A large, radical change proposal threatening present structure will not only increase the size of the collective, bringing in more and external participants, thus making the decision process cumbersome and less efficient, but also cause more goal heterogeniety among its members. This may be sometimes counteracted by a common overall value/goal system of all or part of the decision collective. Decision collective effectiveness depends on its size, efficiency and goal commonality.

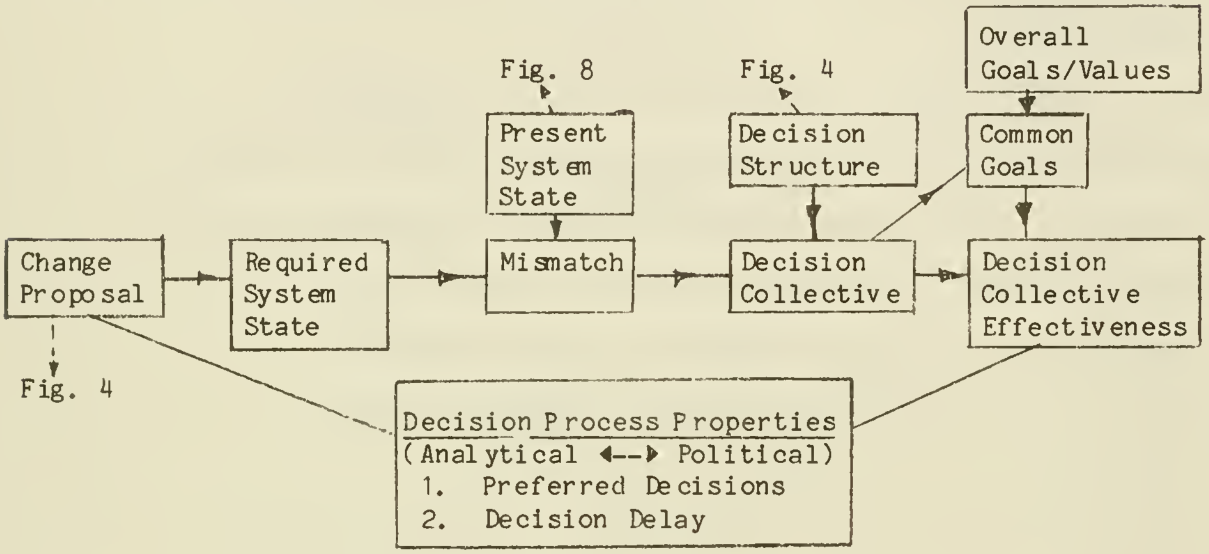
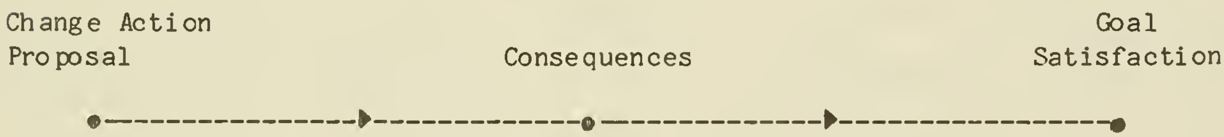


Figure 5 Decision Process Determinants

There is a basic difference between operational and non-operational goals. Following Simon's difinition (5, pp. 155-156) a goal is operational only if there is an apparent way to connect goal satisfaction with the consequences of proposed actions.



Operational Goal

According to Simon a collective decision process will be predominantly analytical if decision collective members have common operational goals. Otherwise decision will be reached by predominantly bargaining processes.

Radical or large change proposals involve substantial or even large uncertainty. Therefore, their predicted consequences and contributions to goal satifaction are vague and doubtful. Hence, even if the decision collective has common goals, they can not be operational with respect to radical change proposals.

To sum up, change proposal properties and decision collective effectiveness togther determine the properties of the decision process for a specific proposal. The following process attributes, paraphrasing Mack's attributes (6), will help in discerning decision process type:

1. Decision collective size, homogeneity, and efficiency.
2. Decision demands on rational capacity, objectivity and perseverance.
3. Decision collective attitude toward and aptitude for radical change.
4. Consequences of action, clear or vague.
5. Goals connection to action consequences, clear or vague.
6. One of a kind or statistical decision.

The interaction of these attributes to discover existence (or non-existence) of common operational goals in shown in Figure 6. In cases where all the above attributes tend to be well-structured the process will be mostly rational. The more any or all the attributes tend to be poorly structured the more political the process will become.

Operationally, the decision process is characterized by the type of decisions it prefers (small/large, normal/radical) and by the time required to arrive at a decision (Decision delay). The dependence of decision outcome and decision delay on the decision process determinants is shown in fig. 7.

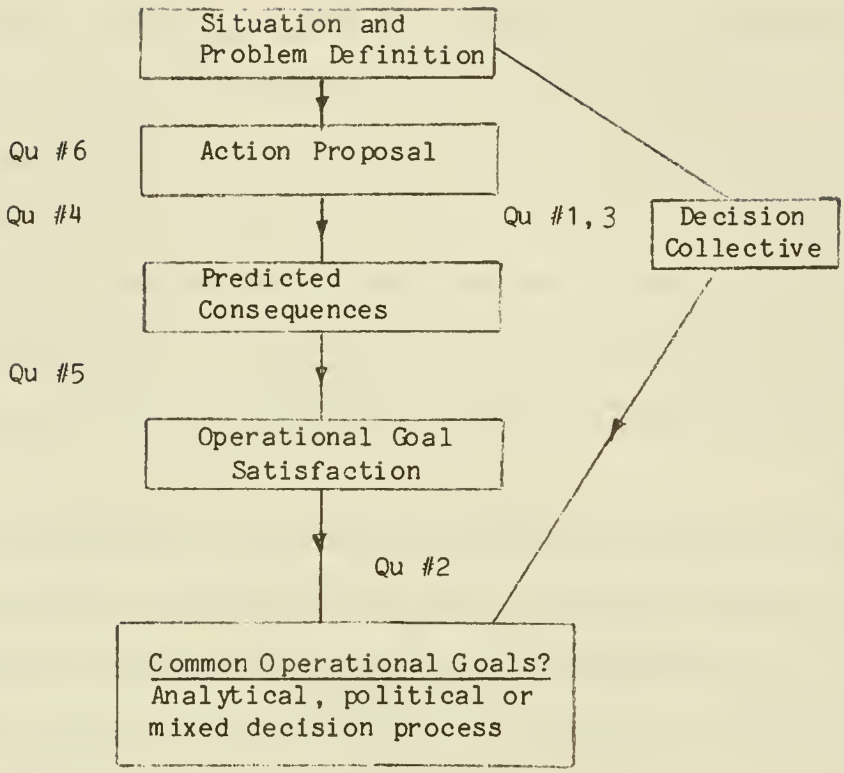


Figure 6

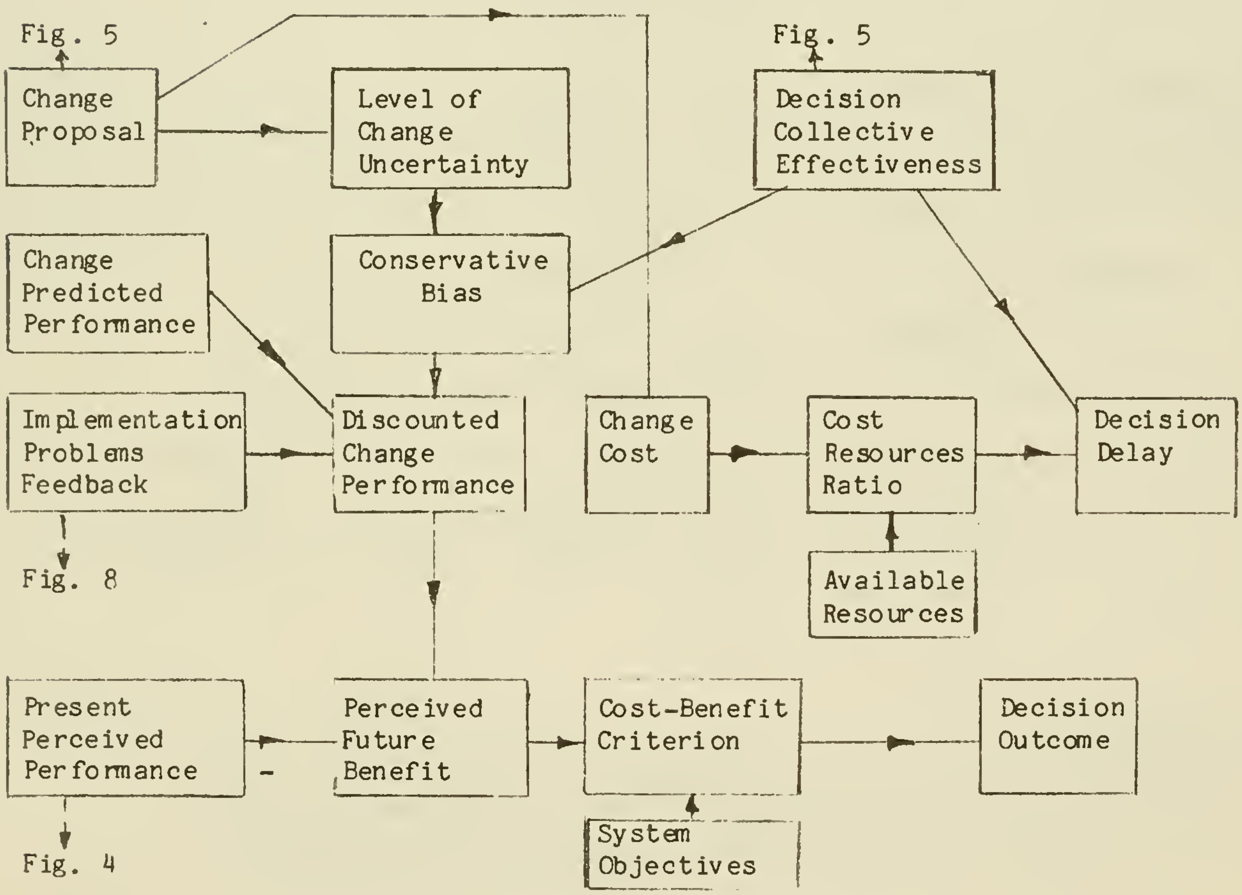


Figure 7 Decision Outcome and Delay

When the consequences of proposed changes are vague (Qu. #4,5) due to various uncertainties, a typical situation for an innovative radical change proposal, the decision collective exhibits a conservative bias against it (6, pp. 122-129). This bias increases with decrease in effectiveness of the decision collective. The conservative bias causes a discount in the value of the change proposal predicted performance, tipping the scale in favor of the status quo or of lower uncertainty and wider concensus proposals.

The less effective the decision collective is, the more it would tend toward incremental, low risk (uncertainty) decisions; tending in the purely political process toward disjointed incremental decisions[1] (Lindblom, 7).

The same variables, decision collective effectiveness and change uncertainty also influence decision delay. This delay increases with increasing proposal cost/available resources ratio.

6. The Implementation Process

The details of the implementation process, its stages and problems vary very considerably between different systems. Here we shall describe a simplified aggregate model, reserving detailed discussion for another paper. This simplified model is similar in part to Pathak's model (8).

The implementation process model is shown in Figure 8. The nominal implementation rate is determined by the required change (system-change mismatch) and by the available resources. Problems which occur during implementation are of two types.

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[1] A disjointed incremental decision amounts to a small change dealing with a small part/few dimensions of the system. This is much easier to get through due to smaller decision collective and consensus requirements.

1. Normal debugging and learning problems associated with introducing new equipment and procedures which increase with change uncertainty.

2. Resistance to change induced difficulties due to desired-actual system state mismatch.[1]

Hence, the rate of implementation problems depends both on implementation rate and on system state mismatch. As implementation problems accumulate, more and more effort must be devoted to them, decreasing the effective implementation rate.

Implementation problems have two additional effects. First of all, they reduce system efficiency and performance. Also feedback about implementation problems, magnified and distorted by system members resisting the change, leads to further discount of the impact of the change on future performance.

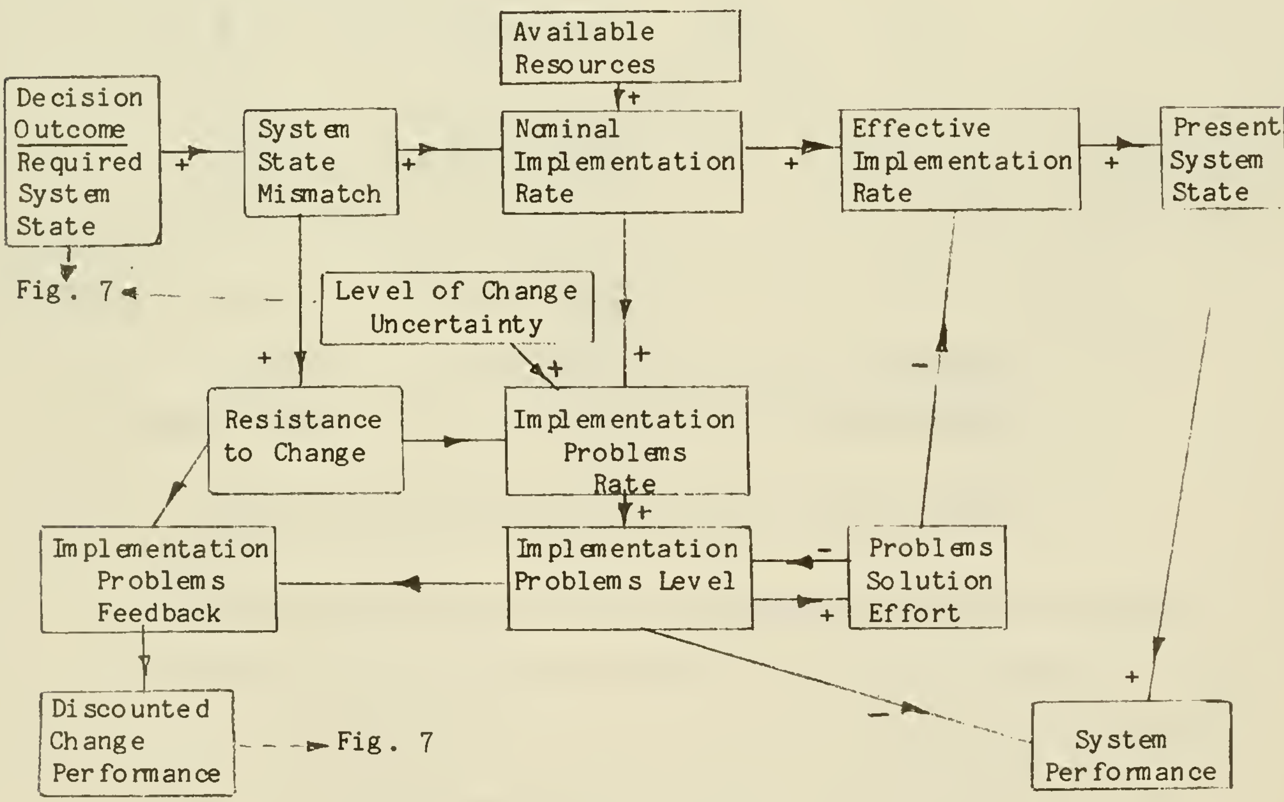

Figure 8 The Implementation Process

[1] Sometimes, one can avoid the resistance to change difficulties by selecting (or creating) an implementing unit matched to the change tasks.

7. Overall Process Model

A combined and aggregated presentation of the overall process is shown in Figure 9. It can be seen that while a STS evolves and adapts in response to its changing environment, the path of evolution in all stages: search, decision and implementation, is constrained and to a large extent determined by present system properties, by the decision structure governing it and by the quality of feedback.

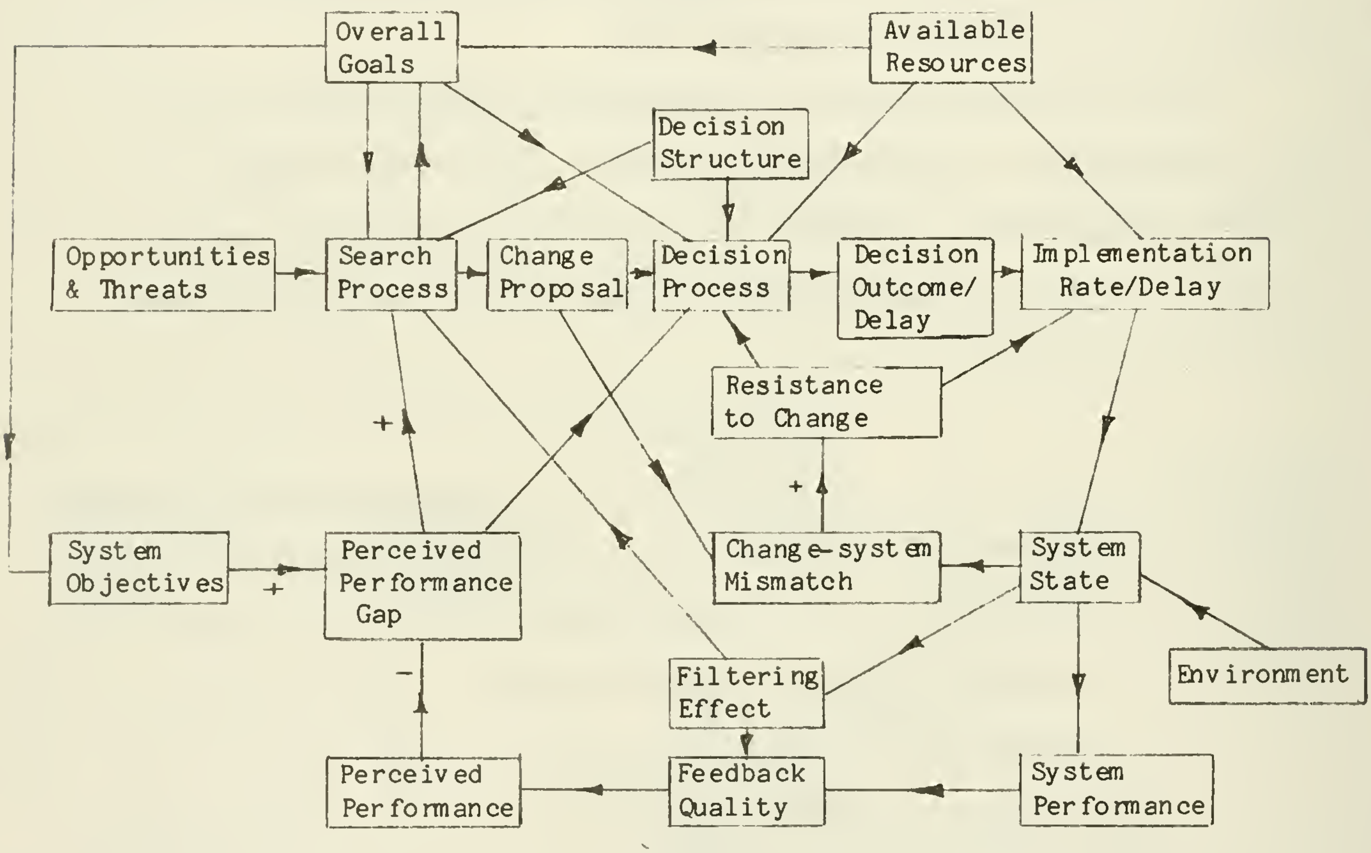

Figure 9 Systems Evolution Process Overall Diagram

Note that the search and decision bodies may be outside the STS itself, in another unit or level of the organization or even without any formal connection to it.

Hence, the selective perception filtering properties of the search, decision and the implementation stages (sec. 3) may be quite different.

For example, as described by Wilson (9) in a large diverse organization there is a considerable variety of change proposals including radical ones. (Wide-band search filter), however its decision process is consensus oriented and blocks major innovations (Narrow-band decision filter).

In other cases the decision process (decision collective, sec. 5) is external and on top of the STS (strong corporate management). It is not affected (perhaps even affected positively) by the suggested radical change (Wide-band decision filter). It may well embark upon it, ignoring problems in the STS itself which will surface during implementation[1] (Narrow-band implementation filter).

Thus, various combinations of all the above factors will lead to very different evolutionary behaviors ranging from the normal evolution process to the radical change process.

8. Processes of Evolution (10)

Normal evolution proceeds within a given framework: Objectives, internal structure, technology and external interfaces; hence, change-system mismatch is small. Radical evolution on the other hand, involves far reaching changes in the existing framework, a transition to a basically different system and environment; hence, change-system mismatch is large. In both cases, normal and radical, the implementation of change is incremental; one cannot change a complex STS overnight. However, the results are very different.

As defined, normal change can usually lead to the following results:

1. Exploiting more efficiently present operating enviroment.
2. Obtaining better performance in a narrower operating environment.
3. Channeling into a dead end.

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[1] GE top management put transistors into its vacuum tube division. The results were not satisfactory.

Pursuit of paths 1, 2, i.e. the path of adaptive speicalization, can lead to a dead end when system environment undergoes large changes. In some cases, where the enviroment changes slowly, the accumulation of normal incremental changes over a long period of time may lead to a radical system change.

Radical, qualitative change if successful, can lead to:

1. Large expansion of present operating enviroment.
2. Transition to a different operating environment.
3. Creation of a new operating enviroment.

Radical change is required in order to cope with large changes in the enviroment of the system.

Recalling STS behavior in response to change (sec. 3) it is evident that mature inflexible sociotechnical systems, operating as narrow-band filters will follow in almost all cases the normal path of evolution. This tendency will be even stronger when the decision structure governing the system is diffuse and heterogenious, causing decision collective ineffectiveness. Radical change, triggered by technological opportunities, changes in the environment or other factors, must therefore find other routes. It will be championed in many cases by newcomers creating new uninhibited organizations penetrating, where possible via empty niches in the enviroment. These, if successful in a relatively stable, possibly new, environment, will in due course optimize their structure to that enviroment; thus, becoming in their turn rigid and unable to accept further radical change.

The evidence supporting these assertions is very impressive and comes from many fields: business firms, military organizations and public insitutions (3, 11, 12, 13, 14, 15).

Only a few examples will be mentioned. The transistor revolution was championed successfully by new companies. The attempts by the old vacuum tube manufactures to move into transistors ended mostly in failure. The diesel electric locomotive was introduced by General Motors, an outsider, and not by the established locomotive manufacturers. The introduction of major military innovations, i.e. ballistic missiles and naval nuclear power, required the setting up of new organizations dedicated to these missions.

A new technology which is applicable to various products and systems will probably be applied, first of all, to apparently promising new stand-alone products and small systems (digital watch, electric typewriter, hand calculator) in many cases championed as described above, by innovative newcomers. These products and their champions serve as the vehicle for transferring the new technology from the laboratory to the first generation of actual use.

The application of new technology to a large mature STS is a slow, incremental, two-stage process

1. Substitution of equipment without changing the overall structure of STS. (3. p. 10).

2. Re-structuring of the STS, including further substitution of old equipment and introduction of new equipment. This process is extremely slow and often not successful.

The substitution of equipment in a large complex STS is a lengthy process stretching over the many years required for development, production and large scale incorporation. Because of this delay, as well as risk aversion behavior common in a mature STS, the new equipment will usually be based on second generation technologies i.e. on technologies which have already been proven in other products or systems.

Moreover, this new equipment, even if based on latest technology, must conform to and function within the existing complex STS framework which is determined by the bulk of older equipment and, last but not least, personnel accustomed to the old methods, equipment and social structure (e.g. the telephone system).

The second stage, where the complex STS is restructured to make a full use of the "new" technology takes place, if at all, much later (possibly a few decades after the "new" (by now old) equipment has throughly assimilated by the STS. Hence, a novel system structure will usually appear many years after the maturation of its underlying technology. This process is illustrated in the following diagram (fig. 10) which shows the delays in the application of new technologies in a complex STS.

The introduction of computers (Electronic Data Processing) into banking illustrates this two-stages process. EDP was introduced via mechanizing account handling and other routine banking operations in the late 50's. However, radical innovative uses of EDP in banking, involving

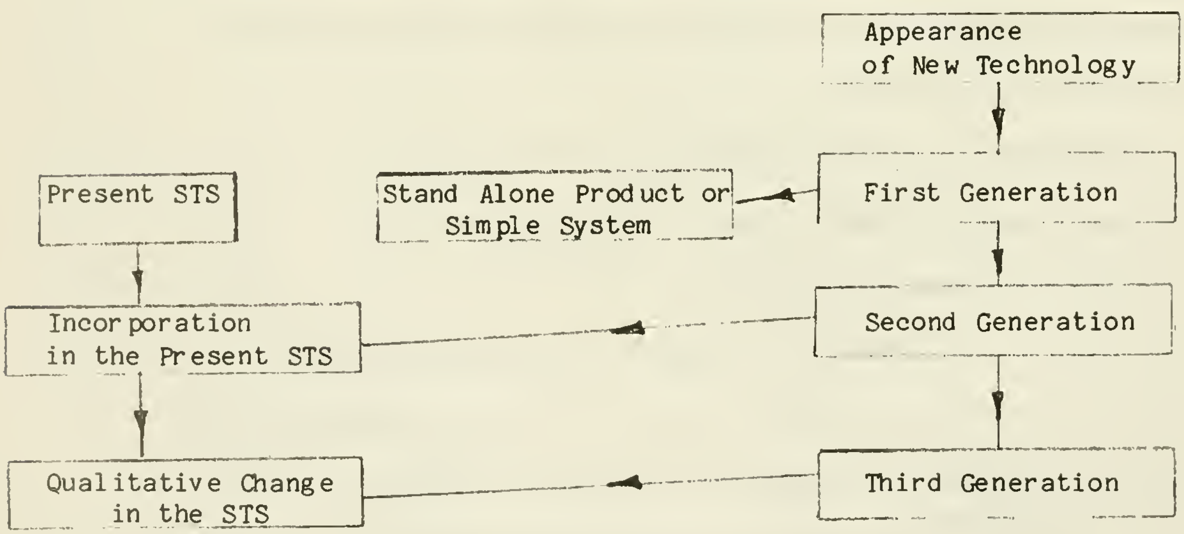

Figure 10

electronic fund transfer and automatic tellers, which may lead to radical changes in banking, have only been introduced during the last few years (16).

Referring to the model, this slow, incremental, staged process reduces change uncertainty and system resistance to change; hence it is the common way of change in mature, structured systems. If the environment changes slowly, this process may be sufficient, however, even in this case its cumulative effects could bring the system to a dead end. On the other hand, in times of crisis, when the environment changes rapidly and system inadequacies become evident suddenly, the situation is basically different, requiring fast adaptation. This cannot be accomplished in most cases as the implementation of radical change in large, complex systems may take decades. Hence, many systems fail under these difficult conditions unless they are strong enough to survive a long period of degraded performance.

The introduction of tank (14, 17) illustrates this situation. After initial success in WWI technical improvement in the tank itself proceeded leading to improved and dominant designs in various countries (for example, the American WWII M4 Sherman tank). However, at the beginning of WWII, the required re-structuring needed to make effective use of tank, i.e. the formation of independent armored forces supported by aircraft designed to fight a blitz krieg was only achieved in Germany. France and England dispersed their tanks in their infantry divisions, incorporating them merely as supported units for the infantry. This led to their defeat in 1940. Thus the introduction of new equipment without system re-structuring led to a dead end.

In summary, the normal evolution of a mature complex sociotechnical system is characterized by

1. Slow, incremental, possibly leading to a dead end.[1]
2. Lag in technology utilization.
3. Very slow adaptation of structure.

9. Conclusion

The description of the process of evolution of a complex sociotechnical system based on the model presented in this paper is rather general and sketchy. It does not deal with the effects of system and decision structure detailed characteristics on the process. Nor does it deal with the interaction between the evolution of several competing/cooperating systems co-existing in the same area.

This paper highlights a serious problem in the evolution of a mature, complex sociotechnical system. Can the process be improved? Is crisis the only way to force change on an inflexible sociotechnical system? These problems require further study.

10. Acknowlegements

The author owes a great deal to fruitfull discussions with Professors Roberts, Schon, Hollomon, Utterback, Von Hippel and other M.I.T. faculty.

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[1] Even more so in systems lacking performance feedback (e.g. military systems in peace-time). This lack destroys the main performance adjustment loop. Hence, the system must find and follow measurable surrogate objectives; these however, may be tenuously connected to the real performance objectives. War often uncovers suddenly large performance gaps which cannot be closed rapidly, thus leading sometimes to catastrophic results.

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