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QUANTIFYING THE SWITCHING MODEL OF VIRTUAL ORGANIZATION

ABBE MOWSHOWITZ, The City College of New York
Department of Computer Science, Convent Avenue at 138th Street, New York, NY 10031, Tel: (212) 650-6161
Email: abbe@cs.ccny.cuny.edu

AKIRA KAWAGUCHI, The City College of New York
Department of Computer Science, Convent Avenue at 138th Street, New York, NY 10031, Tel: (212) 650-6015
Email: akira@cs.ccny.cuny.edu

ABSTRACT

This paper reports on a study of the "switching model" of virtual organization. A computer program (voSwitch) has been developed and implemented as a first approximation to a quantitative version of the model. The switching model interprets virtual organization as a management paradigm, rather than as a particular form or type of organization. In this view, "virtuality" is a matter of degree rather than of kind. That is to say, some functions, processes or structures within a given firm or enterprise may be organized virtually and others not. The switching model captures the flexibility and leverage that can be achieved when managers maintain a strict logical separation between the requirements of a task and the means for satisfying those requirements. Switching is an important element in many definitions of virtual organization in the literature and thus the model offers a useful theoretical framework for empirical investigation of hypotheses about virtual organization. The research described in this paper has two major objectives: 1) to develop a precise, quantitative framework for the switching model of virtual organization that helps to specify the model's domain of applicability; and 2) to demonstrate a quantitative instrument that shows the utility of the switching model and lays the foundation for development of a decision-support tool.

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CONTRIBUTION

The study reported in this paper contributes to IS research by establishing a framework for systematic investigation of virtual organization. This study is arguably the first to quantify the benefits and drawbacks of managing according to virtual organization principles. It makes use of a computer program designed as an instantiation of the switching model of this important management innovation.

The study is also the first to develop a quantitative model of virtual organization that invites empirical investigation to identify relevant variables and adopt measures to collect the business data needed to apply virtual organization methods. Researchers can access the current system on the authors' Website and use it as a tool for investigating hypotheses relating to virtual organization management. The availability of this open source tool is meant to assist in the development of sound empirical knowledge in this area and the program will – if it is widely used and enhanced by other researchers' experience – contribute to the development of best practice guidelines for virtual organization management.

Experiments with the program reported in the paper provide tantalizing evidence of the advantages that can be achieved with virtual organization. It is hoped that these will point the way to and stimulate further experiments, based on a wide range of business problems, that add new requirement and satisfier attributes, and that extend and refine the switching scheme currently used in the program.

This study should be of interest to IS researchers examining the potential benefits of management innovations that rely heavily on the use of information technology. It should be especially interesting to those concerned with the potentiality and implications of virtuality as an organizational principle. Managers may find the program of interest as an instrument for learning about the appropriate use of virtual organization.

INTRODUCTION

Advances in information technology and the emergence of the Internet as a new venue for commerce have been accompanied by innovations in organization and management. Extensive use of computers and communications technologies appears to have created opportunities to develop radically new management strategies. Common to many descriptions of these innovations is the adjective "virtual." Terms such as "virtual organization" (Mowshowitz 1986), "virtual corporation" (Davidow and Malone 1992; Malone and Davidow 1992; Byrne 1993), "virtual team" (Hammer and Champy, 1993; Ishaya and Macauley 1999), "virtual community" (Rheingold 1993), "virtual office" (Giuliano 1982), "virtual classroom" (Hiltz 1986, 1994; Hiltz and Wellman 1997) and others have appeared in the literature since the early 1980s.

The more or less independent adoption of "virtual" by so many different scholars suggests there is a common thread linking the different innovations together. Thus one is justified in seeking a common denominator among the disparate definitions that make use of the qualifier "virtual." It is not uncommon to have many different descriptions and analyses of a complex, new phenomenon and virtual organization is no exception. A strong contender for the title of common denominator for these descriptions and analyses is the *switching model* of virtuality (Mowshowitz 1994, 1997a, 1997b, 1999, 2002), explained below. This model serves to unify the disparate notions of virtuality or virtual organization currently in use among researchers and practitioners. In addition it offers a framework for empirical investigation of hypotheses about virtual organization.

The switching model interprets virtual organization as a management paradigm, rather than as a particular form or type of organization. In this view, "virtuality" is a matter of degree rather than of kind. That is to say, some functions, processes or structures within a given firm or enterprise may be organized virtually and others not. The switching model captures the flexibility and leverage that can be achieved when managers maintain a strict logical separation between the requirements of a task and the means for satisfying those requirements.

Despite its widely recognized importance as an innovation in management and organization, there is a dearth of systematic research on the theory and practice of virtual organization. Descriptions and case studies abound, but apart from the switching model, there are no operational definitions of virtual organization. This model has been shown (Mowshowitz 1997a) to capture the essence of many descriptive or informal definitions (Sieber and Griese 1999) and lends itself to the formulation of empirically testable hypotheses about virtual organization.

As a socio-technical phenomenon, virtual organization has much in common with the role of division of labor in industrialization (Mowshowitz 2002). Division of labor offered competitive advantages in the organization of production that could not be matched by handicraft methods (Simon 1962). As a result, factory methods were adopted by innovative entrepreneurs and eventually displaced the conventional workshop (Braverman 1974; Smith 1976). The evolution of industrialization, especially its twists and turns in the latter part of the twentieth century (Chandler 1977, 1986; Goldman, Nagel, and Preiss 1995; Ohmae 1990; Sabel and Piore 1984; Thurow 1996; Vernon 1980, 1986) is far from a simple phenomenon; but the deceptively simple idea of division of labor has played a pivotal role in that evolution. Virtual organization is quietly playing a similar role today in areas such as supply chain management (Kumar and Christiaanse 1999). It is triggering a fundamental economic and social transformation whose nature and scope need to be better understood.

This paper presents results of an effort to quantify the switching model of virtual organization. A computer program (voSwitch) has been developed and implemented as a first approximation to a quantitative version of the model. Experimental applications of the program are discussed with a view to showing its potential value both as a research aid and a decision-support tool. The exercise itself serves to make the switching model more precise and helps to specify its range of applicability.

WHAT IS VIRTUALITY?

Why have so many observers chosen the word “virtual” to describe innovations in organization and management that have been stimulated by information technology? Formal, dictionary definitions tell part of the story. The Oxford English Dictionary (OED) says "virtual" is something "[t]hat is so in essence or effect, although not formally or actually; admitting of being called by the name so far as the effect or result is concerned." Other dictionaries offer similar definitions: "[e]xisting or resulting in essence or effect though not in actual fact, form, or name" (American Heritage Dictionary); and “being such in essence or effect though not formally recognized or admitted" (Webster's Ninth New Collegiate Dictionary). These definitions capture the idea of *organization in essence or effect* that some users of the word "virtual" mean to convey about contemporary organizational innovations.

The broader connotations of the word are more illuminating. First, “virtual” may suggest an opposition between real and non-real events or entities. Secondly, it may connote an incomplete or emerging event or entity. These two connotations are typically mixed together in varying proportions to characterize specific organizational innovations.

Contemporary organizations present a bewildering array of faces (Davidow and Malone 1992; Lawrence and Lorsch 1967; Malone and Davidow 1992; Mintzberg 1979; Morgan 1986; Scott 1987; Zuboff 1988, Vekatraman and Henderson 1996). They may not conduct their affairs in fixed locations, shifting activities with ease from one place to another or operating in cyberspace; their constituent parts may change from time to time, stimulated by an “internal marketplace” (Turoff 1985), some functions being outsourced or provided by ever-changing partners (Outsourcing Institute 2003); their products and services may exist only in cyberspace; their relationships with personnel may assume a variety of different forms, from traditional employment to short-term contracts; work is often mediated by computer technology (Zuboff 1988) and may be performed in cyberspace or in varying physical locations at different times.

For most of human history organized activities have been associated with specific, identifiable places, buildings, tools, and people. This long experience with organization characterized by tangibility and continuity has led observers of the new modes of organization to invoke the term "virtual" (Burk 1998; Davidow and Malone 1992; Harrington 1991, Malone and Davidow 1992; Venkatraman and Henderson 1996; Rheingold 1993). The tangible or physical entities making up the world of the senses are the stuff of reality. Entities or constructs that seem to differ radically from those defining our familiar physical reality are thus deemed virtual (Harrington 1991). Observers generally agree that the organizational innovations cited above are new and different and somehow virtual (Turoff 1997). But their characterizations of virtuality depend on the particular objects of their attention.

For some observers it is the peculiar venue, namely cyberspace, or the absence of walls or physical boundaries that marks the virtual organization. Others focus on the ever changing cast of characters populating networks of individuals or organizations. Yet others equate virtuality with special kinds of products or services such as Web-based information. Some observers describe virtuality in terms of the evanescent project teams called into being for specific purposes. For others the defining feature is the special role played by clients or customers in determining the organization's output.

Each of these different foci captures some important aspect of virtual organization. However, none is sufficient to characterize the whole phenomenon. An adequate definition must take account of all the major spatial, temporal and structural features implicit in these partial views.

One of the most common applications of the word “virtual” is to organizations without walls (Giuliano 1982; Hiltz 1994; Davidow and Malone 1992). Traditionally, organizations operated in fixed locations, typically within physical structures with very solid walls. The monumental buildings erected to bolster corporate images reinforce the connection of business to the physical world. Similarly, the offices, classrooms and shopping malls that most of us are familiar with are in fixed locations and almost always enclosed by physical walls of some sort. Thus, to describe an organization without walls, it is natural (however misleading) to choose a term suggesting something amorphous and not quite real. This thinking appears to underlie the designations virtual corporation, virtual office, virtual classroom, virtual shop, virtual mall, and similar locutions.

The apparently emergent character of some organizational innovations reinforces the sobriquet “virtual.” Networks of firms, whose membership list changes quite frequently, appear to be emergent entities in a perpetual state of becoming. This type of entity differs from the familiar, stable groupings of the past. For this too it is natural to invoke the idea of virtuality and call such groupings – of small and medium sized firms, distributors, suppliers, contractors, etc. - virtual networks.

Transactions in cyberspace that seem to take place in an ethereal domain without physical dimensions provide another opportunity to invoke virtuality. Operating in cyberspace implies the ability of actors associated with an organization to interact or to conduct conjoint activities with each other without being in the same place at the same time. This ability seems to transcend the constraints of ordinary activities and leads observers to identify a new form of organization.

Established, scientific usage also lends credence to the extension of virtuality to social phenomena. Physicists have long used the term "virtual image" to characterize what one may see in a mirror or though a lens. The notion “virtual work” facilitates computations on static systems that move only in imagination (Feynman, Leighton, and Sands 1963a). “Virtual particles” – unobservable according to the Heisenberg uncertainty principle which asserts the impossibility of simultaneously measuring the position and momentum of a particle with unlimited accuracy (Feynman, Leighton, and Sands1963b) – play an important role in quantum mechanics. More directly relevant to the defining features of virtuality in social settings are the constructs of virtual memory in computer systems and virtual circuits in data communications (Mowshowitz 1997a). All of these notions draw a distinction between concrete and abstract entities, e.g., the concrete storage space of a computer *vs*. the abstract memory referenced by a programmer, a concrete circuit used to transfer a message in a telecommunications network *vs*. the abstract transmission paths that could be assigned to a message.

This distinction between concrete and abstract entities, made explicitly or implicitly (Venkatraman and Henderson 1996), is a common thread in the different conceptions of virtuality. In the school or office "without walls" it does not matter where a function is performed. A teacher may conduct a class by exchanging electronic messages with a geographically dispersed group of students. An office worker may process orders from customers by accessing a database on her company's server using a computer in her home. "Absence of walls" loosens the connection between the requirements of a task and the way those requirements can be satisfied. A school principal is responsible for making courses available to students, but those courses may be taught in a conventional classroom, by old-fashioned correspondence, or by using the facilities of the Internet. These formats represent alternative satisfiers.

The ability to change easily from one means of satisfying a need to another calls for a vision of management that keeps satisfiers and needs at arms length. The split between requirements and satisfiers is the foundation of the managerial freedom afforded by virtual organization. The term "virtual organization" (which alas has been around too long to scrap) is misleading since it suggests a variant form of organization. In fact the innovations of interest are largely in the domain of management rather than organization. The definition of virtual organization used here captures a principle of management – it does not define a new form of organization.

The managerial freedom offered by virtual organization derives from its spatial, temporal and structural characteristics (Faucheux 1997; Porter 1986; Reich 1983, 1992). Spatially, virtual organization offers the freedom of co-locatability and transferability. Facilities and personnel remote from each other can be co-located courtesy of information technology. Exchange of information over the Internet, for example, makes it possible for parties or processes in different physical locations to cooperate. The ability to transfer or shift personnel or facilities is a complementary feature of spatial freedom. Clearly, transferability depends on reliable modes of transportation, but effective use of this freedom depends critically on information technology.

THE SWITCHING MODEL OF VIRTUAL ORGANIZATION

Following (Mowshowitz 1994, 1997a, 1997b, 1999, 2002) we take the concept of a virtually organized task as the cornerstone of virtual organization. Such a task is conceived as a goal-oriented activity whose (abstract) requirements are logically distinct from the (concrete) satisfiers that might be assigned to them at a given moment. A virtually organized task is in effect executed by assigning appropriate satisfiers to its requirements. Assignments and re-assignments are made dynamically over time. These changes (or switches) in the assignment of satisfiers to requirements define the critical innovation of virtual organization, and thus constitute the core of the *switching model*.

Making the assignment is central to the management of a virtually organized task. Such management is also responsible for tracking assignments, analyzing and reviewing requirements, identifying and maintaining lists of potential satisfiers, and (re-) examining the criteria used to assign satisfiers to requirements. An organization may perform some tasks virtually and others in a more conventional way. The virtual approach is not necessarily advantageous in all cases, so an organization can be expected to embrace a mixture of virtually organized and conventionally organized tasks. Thus, being a "virtual organization" is not an all-or-nothing proposition.

The main elements of the model are the following:

R, a set of *requirements* (e.g., raw materials needed to manufacture a product; components used in assembling a product; expertise needed to offer a service; etc.);

S , a set of *satisfiers* (e.g., sources of raw materials; suppliers of parts or components; providers of expertise; etc.)

M_t, a mapping of R to S at time t

This mapping M_t is the *switch* that assigns to each requirement of R one or more satisfiers of S at time t. M_t makes the assignment based on *switching criteria*, i.e., conditions that must be met in making an assignment. These criteria express the benefits and drawbacks of assignments: the potential benefits of a particular re-assignment must exceed the drawbacks of making the switch over a given time period. For example, all other factors being equal, the net gains from reduced production costs of a switch, computed over a period of one year, must be greater than some pre-determined threshold value for reduced production costs over the given period. Switching decisions take account of the relative costs of satisfiers, a key component of production cost, as well as the management costs directly and indirectly associated with (re)assignment of satisfiers to requirements.

The switching model presented here has much in common with dynamic resource allocation models applied, for example, to machine scheduling (Pinedo 1995), vehicle routing (Psaraftis 1995), and driver-to-load assignment (Powell 1996). These models are extensions of classical, static assignment problems such as treated in (Dantzig 1963). In common with many approaches described in the literature, the switching model treats dynamic allocation as a sequence of static allocation problems. Consider the trucking industry application of assigning drivers to loads called in by customers over time. In the switching model framework, loads could be interpreted as requirements and drivers as satisfiers. The assignments (represented by M_t for discrete values of t) describe a sequence.

Switching in a virtually organized task differs from dynamic allocation models in two critical respects. First, the former is much broader than the latter, taking account of a complex managerial process that includes dynamically changing allocation criteria and procedures. The allocation procedure and criteria for making assignments are fixed in dynamic resource allocation models. Allowing for changes in allocation criteria is critical since the switching model is designed to reflect changes in marketplace conditions. The second difference arises from the way cost is handled. In the switching model the cost of managing the allocation process is taken into account in making assignments. As explained later this cost includes resources used by management in maintaining the model itself.

Requirement-satisfier pairs in the switching model must be assigned a *utility value* since the ‘strength’ of the linkage can vary. In the simplest case, the utility value is 1 or 0 representing respectively a feasible and infeasible assignment. Decisions about switching (i.e., changing the current mapping of requirements to satisfiers) are based on a computed value called *switching impedance* that provides a quantitative measure of resistance to change. Changing $M_t(r)$ for a given requirement r of R may call for drawing up new contracts or modifying production tasks to accommodate parts from new satisfiers. Switching impedance has two components: *transaction impedance* and *indirect impedance*. The former is the effort or resources needed to assign a new satisfier to a given requirement; the latter represents a pro rata share of the resources needed to maintain current sets of requirements and satisfiers in the switching model framework. The impedance values used in decisions about switching include costs in the narrow sense, but also take account of reliability and longevity of satisfiers as well as other factors (i.e., database change, legal fees, training, marketplace scanning, information acquisition, staff time, and reallocation overhead) as detailed in the subsequent section “First Approximation to a Quantitative Model” – this explains the adoption of the term “impedance” in the model, rather than “cost.”

In general, the set R of requirements is fixed or changes relatively slowly over time. S, the set of satisfiers, typically changes more rapidly than R (e.g., suppliers appear and disappear in the marketplace). It should be noted that some elements of R or of S may be more stable than others. A set of satisfiers, for example, may consist of subsets of varying degrees of stability. Changes over time in the composition of the sets of requirements and satisfiers must be taken into account. This can be done with the aid of a probabilistic scheme designed to reflect marketplace conditions.

Satisfiers are characterized in voSwitch by the following attributes:

- *unit cost* (price per unit charged by the satisfier);
- *volatility* (measure of expected fluctuation in the satisfier's price per unit);
- *longevity* (measure of the satisfier's stability or the likelihood that the satisfier remains in business over a given period of time);
- *prestige* (measure of the satisfier's brand name recognition);
- *service/product quality* (measure of the quality of the services or products offered by the satisfier);
- *position in the marketplace* (measure of the satisfier's market share for the relevant product or service);
- *functionality* (measure of the capabilities of the satisfier's product or service relative to those offered by competitors);
- *productivity* (estimate of likely increases in satisfier productivity that would result in price reductions over a given period of time);
- *inflation rate* (estimate of the rate of price increase likely to be applied by the satisfier over a given time period).

Requirements are defined by the attributes:

- *importance* (measure of the importance of the given requirement among the list of requirements defining the virtually organized task);
- *persistence* (measure of the stability of the requirement or the likelihood that it will continue unchanged for a given period of time);
- *production volume/level* (measure of the volume of input that needs to be processed in fulfilling the given requirement);
- *tolerance level* (measure of the specificity of the input to be processed in fulfilling the given requirement – the higher the specificity, the greater the difficulty in finding substitutes);
- *overall importance* (measure of the relative significance of the virtually organized task of which the given requirement is a part).

The allowable values for these attributes of satisfiers and requirements, respectively, are given in the section "First Approximation to a Quantitative Model."

The switching model embodies an abstract theory of virtual organization, one that is largely qualitative in nature. The program voSwitch, sketched in subsequent sections, is seen as a first step in the quantification of the theory. An incremental approach to development is deemed necessary because empirical research is needed to obtain the data required to compute impedance values. The current version of voSwitch makes assumptions (based on general economic and business knowledge) about the parameters associated with requirements and satisfiers and about criteria likely to be used in switching decisions. This approach provides an opportunity to demonstrate the potential power of the model to assist managers in improving business performance, and indicates the steps required for further development of voSwitch.

APPLICATIONS OF VOSWITCH 1.0

Any particular implementation of a program designed to provide an ability to compare fixed and switched approaches to management requires specification of the detailed functioning of the tracking, switching and related activities that comprise the management of virtually organized tasks. Before presenting details of the current implementation, two examples are given to help clarify the main functions and uses of the program. The examples discussed in this section utilize a first approximation to voSwitch; they are designed to show what such a program could do and how it could be used to advantage as a decision support tool. To emphasize its character as a first step in the implementation of the switching model, the qualifier 1.0, meaning first version, is appended to the name of the program.

An extended version of voSwitch 1.0 could serve as an analysis and decision support tool for real business environments. As a first indication of how such a program might be used, consider the (real) case of managing the assignment of instructors to the courses offered by a university department. Finding an optimal or near-optimal solution to this problem is non-trivial. Taking account of current staff salaries and other cost data from the Department of Computer Science at City College voSwitch 1.0 is used to compare the results of the virtual organization and conventional management approaches to the staffing problem.

The Department of Computer Science, like many academic departments, has for some time made use of contract employees (mainly graduate students and adjunct lecturers) to supplement the regular faculty in meeting its teaching requirements. One reason for this is to make it possible to reduce the teaching obligation of regular faculty members who have been successful in obtaining external funding for research, curriculum development, and related projects. External funding typically has an overhead component that goes to the College, part of which can be used to pay the salaries of contract teachers. So, the salary of an adjunct, for example, can be offset by the revenue (opportunity cost) derived from a one or two-course reduction in a faculty member’s teaching load for a given semester.

This staffing problem lends itself quite nicely to the switching model implemented in voSwitch 1.0. In particular, the problem can be represented as an assignment of a set of concrete satisfiers (specific faculty members and contract teachers) to a set of abstract requirements (courses). This is a classic example of a virtually organized task. Courses to be offered and regular faculty change over time, but are relatively stable, while contract teachers vary from semester to semester. Reassignment of satisfiers (switching) may occur mainly because the costs of satisfiers may change and the composition of the set of satisfiers itself may also change.

The key to formulating this virtually organized task is cost relative to performance, i.e., minimizing the expenditures on contract teachers together with the opportunity costs of regular faculty members assigned to courses while maximizing the overall quality of instruction. For purposes of illustration, the task is limited to a set of lower level courses that can be taught by a variety of instructors including regular faculty members (assistant, associate or full-professors), adjuncts, and graduate students. Compensation of contract teachers is typically based on experience. As noted above, the cost of assigning a regular faculty member to a course is taken to be the opportunity cost associated with external funding, since regular faculty are paid the same regardless of how many courses they teach in a given semester.

In relation to teaching assignments, opportunity cost has two major components:1) amount of outside funding a professor could obtain if he/she were given a reduced teaching load; 2) value of prestige resulting from publication of papers in exchange for release time. The second component is difficult to estimate, but a reasonable estimate for the first component can be obtained by looking at research grants on which faculty members have served as principal investigator and by fixing the cost of a one-course reduction in teaching load for professor P as the amount of overhead to the college that would be foregone if P does not get the release time. Opportunity cost for professors with no grants (and low prospects for getting grants) is taken to be negligible, meaning such professors are free with respect to contract teachers, and thus will be assigned the maximum course load allowed by the current contract.

In general, grant history, dollar amount of most recent grant, number of publications in the past year, and administrative functions are the main factors used in making decisions about teaching loads. For instance, if a professor P does not currently have a grant, but has had one in the last year, professor P might be given a unit cost value that is close to the going rate for an adjunct. In the example described here, the only factor taken into account is the overhead associated with grants.

The computational model underlying the program relies on probability estimation for some requirement and satisfier attributes and uniform scaling for other attributes. This approach allows for quantifying the elements of the switching model, as explained in more detail in the next section.

The three courses (abstract requirements) shown in Table 1 below are offered each semester by the Computer Science Department. The first one (CS 100) is an elective course; the remaining two (CS 102 and CS 212) are core courses in the computer science curriculum. Each course is characterized by the attributes persistence, tolerance level and overall importance, with values as indicated in Table 1. Importance, defined in the previous section, has not been implemented in voSwitch 1.0 so is absent from Table 1. The persistence attribute is a probability value between 0 and 1; tolerance level and overall importance are ordinal variables that take on values between 1 (least) and 5 (most). Since the courses are quite stable, they are all given persistence value 1.0; and inasmuch as little change is expected in the resources needed to offer them, the courses are assigned the productivity value 1. Differences arise between the courses on the other two attributes. The tolerance level (or difficulty of finding alternative instructors) increases with the level of the course. Similarly, the overall importance (or significance for the computer science curriculum as a whole) also increases with the level of the course.

Impedances in this example are measured in dollars. Direct and indirect impedances (incurred in re-assigning instructors to courses) are estimated as follows: 3.8 (thousand dollars) for database change, 2.0 for legal fees, 1.6 for training, 1.5 for marketplace scanning, 1.4 for information acquisition, and 18 for staff time. The overhead attributable to switching accounts for 3% of the direct and indirect impedance.

On average the department has a constant pool of two adjuncts and four (two beginning and two advanced) PhD students who teach these three courses. These make up the concrete satisfiers in the virtually organized task. There are two faculty members who register a preference for teaching CS100, three faculty members for CS102, and three faculty members for CS212. The allocation problem can be stated as follows: the Department should like to assign one of the two beginning PhD students to teach CS100 and the other one to teach CS 102, and to make the most cost effective assignment by selecting among all the available instructors in the department. Table 2 shows the attributes and their associated values for each of the available instructors for the three courses. These attributes represent characteristics of an instructor (satisfier) in a market context that influence impedance values over time. Note that volatility takes on (ordinal) values between 1 (highest) and 5 (lowest), while both quality and functionality take on values between 1 (lowest) and 5 (highest); longevity, productivity and inflation rate are rated in numbers between 0 and 1. Prestige and position in the marketplace, defined in the previous section, are not used in voSwitch 1.0 so are omitted from Table 2.

Figure 1(a) shows the result of voSwitch1.0 execution for a period of 20 semesters, i.e., the experiment is divided into cycles corresponding to academic semesters. The cumulative impedance incurred by teaching assignments over this period is about 50 thousand dollars.

Results for Staffing Courses

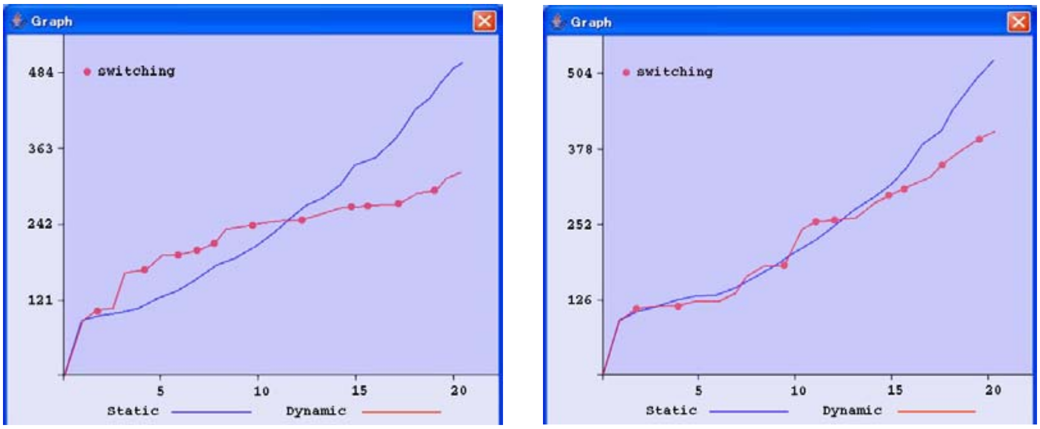
Teaching assignments were changed (i.e., switching occurred) 11 times in the course of the experiment. The result shows relatively high impedance for the switching policy in the first 10 semesters or so. The switching case however outperforms static assignment after about 12 semesters of execution. Over the entire 20-semester period, the switching based assignment is better by more than 15 thousand dollars. The main reason for the relatively high impedance in the early stage is the high volatility values assigned to PhD students. Figure 1(b) is obtained by assigning the lowest volatility and highest longevity values (0.95) to all PhD

Table 1. Courses (Abstract Requirements) with Attribute Values

Course	#sections	Persistence	Productivity	Tolerance Level	Overall Importance
CS100	2	1.0	1	2	3
CS102	3	1.0	1	3	4
CS212	2	1.0	1	4	5

Table 2. Teachers (Concrete Satisfiers) with Attribute Values

Instructors	Cost (K$)	Volatility	Longevity	Quality	Functionality	Productivity	Inflation Rate
PhDSt.-1	2.5	5	0.80	3	3	0.05	0.025
PhDSt.-2	3.1	4	0.85	3	3	0.04	0.022
PhDSt.-3	3.8	4	0.85	3	4	0.06	0.018
PhDSt.-4	3.8	5	0.95	4	4	0.05	0.017
Adj-1	2.9	4	0.95	4	4	0.04	0.020
Adj-2	4.2	5	0.75	5	5	0.07	0.011
FullProf-1	7.9	3	1.0	4	4	0.09	0.016
FullProf-2	7.9	1	1.0	5	4	0.08	0.016
FullProf-3	0	1	1.0	3	3	0.05	0.016
AsscProf-1	6.1	2	0.95	4	5	0.07	0.024
AsscProf-2	6.3	1	0.95	5	5	0.09	0.024
AsscProf-3	0	1	1.0	4	5	0.06	0.024
AsstProf-1	5.1	1	1.0	4	5	0.08	0.022
AsstProf-2	5.1	2	0.85	5	5	0.06	0.022
AsstProf-3	4.8	3	0.75	5	5	0.05	0.022



(a)

(b)

Figure 1. Comparative

students. Switching occurred only 9 times in this case. While the cumulative impedance of the switching policy outperforms the conventional approach by about 10 thousand dollars - slightly less than in the case of Figure 1(a) - the observed impedance in the first few semesters is close to and sometimes lower than that of the static assignment. This case shows that by adjusting the attribute values the switching approach to teacher assignment can be made to achieve more consistent results throughout the period of the experiment.

As shown in the foregoing application, voSwitch can be used to assess the switched and fixed protocols for staffing courses in a traditional university environment. It could also be used to investigate teacher assignment protocols in schools (such as profit-making universities and some business schools attached to traditional universities) that have very few or no permanent faculty members.

A second (hypothetical) case offers a more business-oriented example. Consider the following problem: a management team of a manufacturing company, Widget Works, Inc., is planning to increase the volume of production of one of their products, to wit, "widget X." The objective is to acquire higher market share with reasonable production cost for the next 36 months. The duration of a cycle in this case is one month in the life of the company. Widget X has two components A and B that are purchased from outside suppliers. Management's analysis shows the requirement persistence to be 1.0 and overall importance to be 5. The tolerance level is rated 3 as the company keeps four months stock of these components.

Component A has four potential suppliers (A1, A2, A3, A4), and B has three (B1, B2, B3). Therefore, the problem is (re-)assigning suppliers to components A and B from (initially) four and three suppliers, respectively. Table 3 lists the parameters associated with each of these suppliers (concrete satisfiers).

Direct and indirect impedances associated with switching (aimed at improving the company's profit for widget X's) are estimated as follows: 30 (thousand dollars) for database change, 12 for legal fees, 16 for training, 20 for marketplace scanning, 12 for information acquisition, and 54 for staff time. The overhead attributable to switching accounts for 5% of the direct and indirect impedance.

The experiment was performed to compare the results of a fixed set of assignments with a dynamic supplier allocation protocol. Figure 2 illustrates the cumulative impedance computed by voSwitch 1.0 over 36 months. Supplier reallocations were observed fourteen times over this period, and from the 19th month, the switching business model generally outperforms the static protocol. In this experiment impedance values are expressed in imputed monetary units. The units are imputed in the sense that

Table 3. Suppliers (Concrete Satisfiers) with Attribute Values

Suppliers	Cost (K$)	Volatility	Longevity	Quality	Functionality	Productivity	Inflation Rate
A1	8	High	High	High	High	0.01	0.025
A2	9	High	Low	Medium	High	0.02	0.022
A3	7	Low	Medium	Medium	Medium	0.06	0.018
A4	6	Medium	Low	Low	Medium	0.05	0.017
B1	3	Medium	High	High	Medium	0.01	0.020
B2	5	High	High	High	High	0.02	0.011
B3	4	Low	Medium	Low	Medium	0.09	0.016

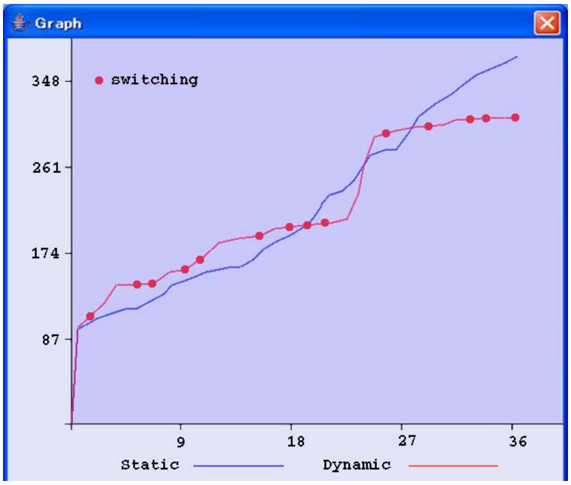


Figure 2. Production Cumulative Impedance Estimate

the computed impedance values are influenced by a variety of qualitative as well as quantitative factors. That is to say derived or imputed monetary figures are commingled with explicit monetary figures relating to costs or prices charged for goods or services. The final impedance difference is estimated to be more than 50 thousand dollars, representing an imputed cost savings of approximately 14%.

The switching model of virtual organization offers a framework for investigating hypotheses and quantifying comparisons with conventional management. voSwitch1.0 is a first attempt to quantify the model. The current state of the program can be viewed as a basis for building a realistic model that is informed by empirical research on the quantitative benefits and drawbacks of switching in commercial applications. In particular, empirical studies could be used to derive realistic attribute values and allocation procedures to be incorporated into the switching model.

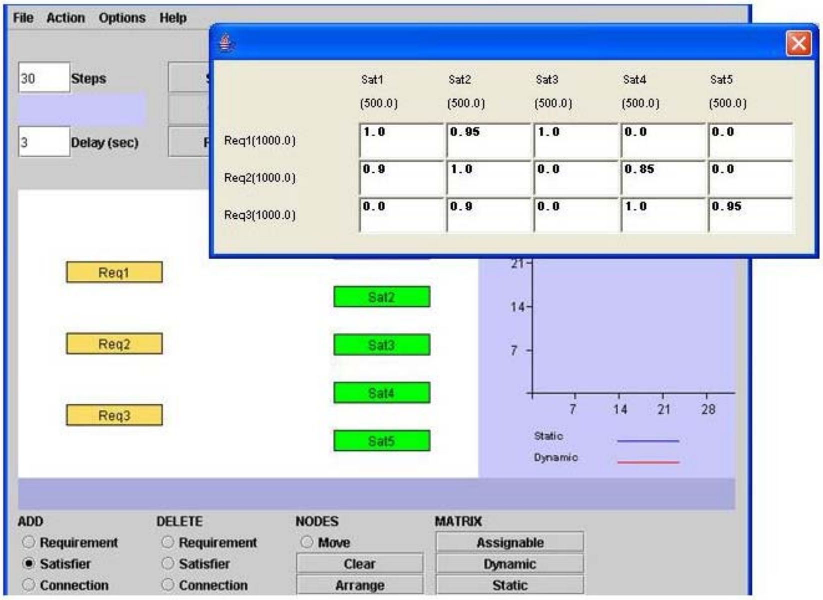
FIRST APPROXIMATION TO A QUANTITATIVE MODEL

The principal objective of the voSwitch software system developed in this research is to create a computational model suitable for demonstrating the essential features of virtual organization and the management practices needed for its realization. This system mirrors the structure of the switching model of virtual organization and provides a foundation for hypothesis testing in decision making. The current version of the system (voSwitch 1.0) is intended as the first step in realizing the objective stated above. There are three steps in running voSwitch 1.0.

STEP 1: The first step requires the user to specify a collection of requirements (R) for a virtually organized task together with the satisfiers (S) that could potentially fulfill those requirements. Requirements and satisfiers are input by the user and are represented on the screen in the form of boxes – requirement boxes are displayed on the left, satisfier boxes on the right. As shown in Figure 3, voSwitch 1.0 records the relationship between requirements and satisfiers in a *reference matrix* (or assignment table) showing which satisfiers can be assigned to which requirements with certain confidence levels, called *capability measures*. The capability measure is a normalized value between 0.0 (absolutely infeasible) and 1.0 (absolutely feasible) and is used to determine an optimal assignment among the feasible ones.

The program uses the reference matrix to make a particular assignment of satisfiers to requirements. For example, let T be a task whose output is a component of a product sold by some company. Suppose the company implements T as a virtually organized task with requirement set R = { R1, R2,..., Rn }. Furthermore, suppose that S = { S1, S2,..., Sm }is the set of satisfiers that can meet the requirements of R. (The assignment table contains information such as R2 can be satisfied by S1 or S3 having capability measures 0.9 and 0.95, respectively, where all other Si’s have capability measure 0). With the information in the assignment table, voSwitch 1.0 finds the best assignment of satisfiers to requirements, i.e., one that minimizes the unit impedance of the components generated as the output of task T.

This problem is deceptively simple inasmuch as it appears at first glance to involve nothing more than finding an optimal matching between two independent sets of elements. However, the problem is complicated by the dynamically changing character of the satisfiers and requirements. In particular, the *persistence* of requirements or the *longevity* of satisfiers may lead to changes over time, meaning that after a period of time, a satisfier Sj may cease to be an allowable option for requirement Ri, because, say, the company providing Sj's capabilities goes out of business. In this case, a replacement satisfier would have to be found for the requirement currently met by Sj. The assignment of a replacement satisfier is an instance of switching. The system thus enables the user to reflect such instability (on a scale of one to five) for each of the requirements and satisfiers. In principle, the size of the assignment table should vary in a probabilistic manner so that the size of S changes more rapidly than the size of R. However, the current implementation voSwitch 1.0 is not capable of augmenting R and S by generating new requirements and satisfiers.



30 Steps

3 Delay (sec)

● Satisfier

	Sat1 (500.0)	Sat2 (500.0)	Sat3 (500.0)	Sat4 (500.0)	Sat5 (500.0)
Req1(1000.0)	1.0	0.95	1.0	0.0	0.0
Req2(1000.0)	0.9	1.0	0.0	0.85	0.0
Req3(1000.0)	0.0	0.9	0.0	1.0	0.95

Figure 3. voSwitch 1.0 Input Interface for Reference Matrix

STEP 2: The second step, calls on the user to define the properties of requirements (R) and satisfiers (S). The program uses these properties to establish the best initial assignment of satisfiers to requirements and to perform switching (i.e., reassigning satisfiers to requirements) dynamically. Specifically, each requirement Ri needs to be defined with a set of attributes like importance, persistence, and tolerance levels. For instance, the importance of a requirement does not relate to any specific satisfier, but to the criteria for switching. If the overall importance of a given requirement is low, the threshold for switching may be raised because there are always unpredictable consequences, and the risks posed might inhibit switching even if a small advantage could be gained. Similarly, each satisfier Si has a set of attributes such as unit cost and longevity, and a probabilistic model is used to characterize impedance which may gradually increase or decrease thus reflecting changes in the satisfier's response to or position in the marketplace. Requirements may be grouped into several classes for purposes of making assignments.

STEP 3: The third step requires the user to specify direct and indirect switching impedances. Switching impedance, like transaction costs (Williamson, 1985), can be direct and indirect. Direct switching impedance derives from the 'cut-and-paste' operation of exchanging one satisfier for another. These include: database changes (e.g., accounting, purchasing, receiving, etc.), legal adjustments (e.g., drafting new contracts), and the training of staff to handle new satisfiers. The 'cut-and-paste' action indicates the business environmental change triggered by the experimenter. It is also possible to enlarge the set of changes to encompass automated events such as contract changes occurring at predefined intervals, arrival of new personnel in a company who require training, and so on. This direct impedance is a consequence of switching. For example, there is a non-zero probability that legal adjustments will be incurred when a switch is made for a given requirement. A portion of the direct impedance will be taken into account in switching decisions to identify opportunities for advantageous switching while at the same time guarding against excessive switching.

Indirect impedance takes account of the overall initial capital investment in the stage of configuring a task in virtual organization, and voSwitch 1.0 charges this impedance at the beginning of execution. Indirect impedance is incurred in maintaining the satisfier set, scanning the marketplace, obtaining information, etc. These activities typically involve the expenditure of staff time.

After these three steps have been taken, voSwitch 1.0 is ready to execute. At the start, the program allocates a specific satisfier to each requirement by computing maximum cost-benefit for the overall system. The system converts various qualitative ratings (specified as properties of a requirement) into a quantitative unit impedance value for a given requirement, e.g., high quality level of the requirement results in higher unit impedance value of that requirement. A similar conversion is done for satisfiers. The ratings specified for satisfiers are used to characterize the dynamic behavior of the environment and to determine feasible assignments of satisfiers to requirements under the specific conditions set by the stochastic processes described below.

voSwitch 1.0 repeats allocations for a specified number of cycles. In each cycle, the system re-configures the sets of requirements and satisfiers (as some of the latter may drop out), and re-computes optimal allocations. An allocation is revised if the system finds that a smaller unit impedance can be achieved for a given requirement by assigning a different satisfier. However, the system needs to charge indirect impedance as well as a (specified) portion of direct impedance for this reallocation. The final result of an experiment is a comparison of production impedance per unit of output under conventional (fixed) *vs.* virtual (switched) regimes.

User Interface Implementation

A Java-based discrete event-driven program is employed to assess the overall benefits and drawbacks of an instance of switching-based management under conditions of change linked to external or internal factors (voSwitch 1.0 is accessible at http://www-cs.engr.ccny.cuny.edu/~project). The optimal switching assignments are dynamically adapted to these changing conditions.

Figure 4 illustrates voSwitch 1.0's user interface for the specification of requirements and satisfiers. By clicking on a box representing a requirement (satisfier), the user can open a window and enter the properties of the requirement (satisfier). Allowable assignments are shown as lines joining boxes on opposite sides of the screen; the current assignment is indicated by highlighting the color of (active) satisfier boxes.

In addition to the reference matrix showing allowable assignments of satisfiers to requirements, voSwitch 1.0 maintains the *current condition matrix* that indicates the assignment of satisfiers to requirements for the current cycle of an experiment. Normally there is at most one satisfier linked to a given requirement, but it is possible to have more than one satisfier linked to a given requirement. (For example, a part could be supplied by two different companies, each furnishing some percentage of the total.) The information in the reference matrix and the current condition matrix is displayed in graphical form. In both cases, requirements and satisfiers are represented as boxes on the screen. The graph of the reference matrix has a line joining a requirement to a satisfier corresponding to an allowable assignment as recorded in the matrix; the graph of the current condition matrix has a line joining a requirement and a satisfier if that assignment is currently in effect.

The reference matrix is initialized at the start of program execution; the current condition matrix changes each time switching occurs. If the requirement Ra is assigned satisfier Sa from the set {Sa, Sb, Sc, Sd} in the previous cycle of the experiment, and Sc is assigned in the current cycle, then the line that connected Ra and Sa in the previous cycle will be erased and a new line connecting Ra and Sc will appear on the screen.

The output of the program is a graph showing two plots of impedance as a function of time: one plot traces the impedance values under the switching regime; the other shows the values under a fixed regime, i.e., where there is no change in the assignment of satisfiers to requirements specified by the user. The output is produced progressively - a new point is added to the graph and the plot line extended for each successive cycle in an experiment.

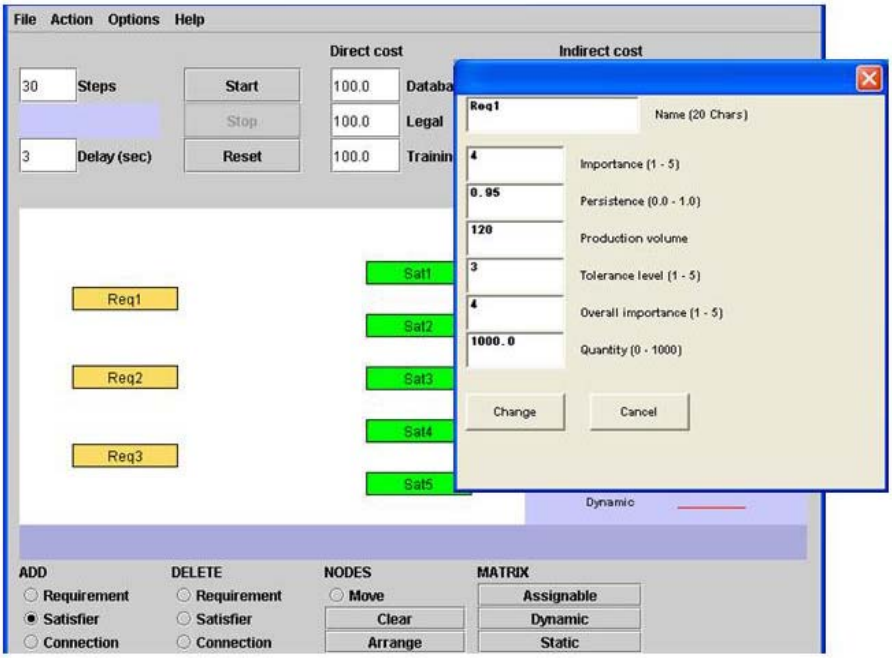
Definition of Satisfiers and Requirements

Satisfiers are currently characterized by the following ten attributes:

S.1 name: string with maximum 20 characters;

S.2 unit cost: integer;

S.3 volatility measure: integer between 1 (highest) and 5 (lowest);



30 Steps
3 Delay (sec)
100.0 Databa
100.0 Legal
100.0 Trainin

Req1 Name (20 Chars)
4 Importance (1 - 5)
0.95 Persistence (0.0 - 1.0)
120 Production volume
3 Tolerance level (1 - 5)
4 Overall importance (1 - 5)
1000.0 Quantity (0 - 1000)

ADD
○ Requirement
● Satisfier
○ Connection

Figure 4. voSwitch 1.0 Input Interface for Satisfier

S.4 longevity: floating point probability value between 0 and 1;

S.5 prestige: integer between 1 and 5, **not used in voSwitch 1.0;**

S.6 service/product quality: integer between 1 (worst) and 5 (best);

S.7 position in marketplace: integer between 1 and 5, **not used in voSwitch 1.0**;

S.8 functionality: integer between 1 (worst) and 5 (best);

S.9 productivity: floating point probability value between 0 and 1;

S.10 inflation rate: floating point probability value between 0 and 1.

The unit cost of a satisfier (S.2) is independent of requirements. It is specified for each satisfier, and altered 'at random' according to the volatility (S.3) of the satisfier itself. Different satisfiers will have different pricing structures. So, satisfier A may charge less than B when the number of units purchased is low, but A may charge more per unit than B if the number of units purchased is high. The volatility rating (S.3) defines a threshold for this change. Specifically, the unit cost (S.2) is multiplied by the productivity parameter (S.9) when the volatility rate (S.3) exceeds a given threshold value. The longevity probability (S.4) is used to determine if a satisfier continues to exist in the system. voSwitch 1.0 applies Bernoulli trials for this determination. The service/product quality (S.6) not only influences the assignment of a satisfier to a requirement (as explained below in the discussion of requirements), but is also used to weight the unit cost value (S.2) in a linear combination with the functionality rating (S.8) of the satisfier. Furthermore, the inflation rate (S.10) is used to modify unit cost for every decision cycle of the execution.

Requirements currently have 6 attributes:

R.1 name: string with maximum 20 characters;

R.2 importance: integer between 1 (most) and 5 (least), **not used in voSwitch 1.0;**

R.3 persistence: floating point probability value between 0 and 1;

R.4 production volume/level: integer;

R.5 tolerance level: integer between 1 (least) and 5 (most);

R.6 overall importance: integer between 1 and 5.

Requirements are generally more stable than satisfiers, and this is reflected in the probability distribution specified for the persistence attribute (R.3). To be considered for assignment to a requirement, the service/product quality (S.6) of a satisfier must meet the tolerance level of the requirement (R.5). The overall importance (R.6) of a requirement does not relate to any specific satisfier, but to the criteria for switching. If the overall importance of a given requirement is low, for example, the threshold for switching may be raised because there are always unpredictable consequences, and the risks posed might inhibit switching even if a small advantage could be gained. voSwitch 1.0 uses a threshold value of 3 for switching, i.e., a requirement with value less than 3 will retain the satisfier initially assigned.

Definition of Switching Impedance

voSwitch 1.0 takes account of seven components of switching impedance, each of which represents an expenditure of resources in modifying the mapping of requirements to satisfiers. These components are:

C.1 database change (integer);

C.2 legal work (integer);

C.3 training of staff (integer);

C.4 marketplace scan to track potential satisfiers (integer);

C.5 information acquisition for requirements analysis (integer);

C.6 staff time in overall management of the virtually organized task (integer);

C.7 reallocation overhead (integer).

Values for these impedance components may be entered by a user through a panel just below the assignment matrix. C.1 through C.3 are categorized as direct impedance components; C.4 through C.6 represent indirect impedance components. C.7 indicates a portion of the direct impedance incurred for satisfier reallocation.

voSwitch 1.0 assigns the lowest impedance feasible satisfier for a given requirement. Recall that possible (unconstrained) assignments of satisfiers to requirements are recorded in the reference matrix that is instantiated with user-supplied data. The initial optimal impedance assignment is computed using the reference matrix at the outset of an experiment. This impedance consists of an *initial switching impedance* and an *optimal assignment impedance*. The former is defined using a list of switching impedance entries, such as initial switching impedance = C.1 + C.2 + C.3 + C.4 + C.5 + C.6. The latter, an optimal assignment impedance, is computed by adding up the components required to achieve the best assignment to a particular requirement of a satisfier chosen from the set of possible satisfiers specified in the reference matrix.

Recall also that as a rule, the assignment of a satisfier to a requirement is considered feasible only if the satisfier has service quality level (S.6) higher than or equal to the requirement's tolerance level (R.5). The best assignment has the smallest weighted unit impedance, defined as *weighted unit impedance* = S.2 * (5/(S.6*2) + 5/(S.8*2)). This means that the satisfier's unit impedance increases linearly if the satisfier's quality and functionality measures are rated low.

As an example, suppose that a certain requirement has three possible satisfiers { Sa, Sb, Sc }in the reference matrix prepared by the user with capability measures Sa 0.90, Sb 0.95, and Sc 1.00, so that Sc has the highest capability overall to satisfy the target requirement. Suppose also that the requirement's tolerance level is 4 and service quality levels of Sa, Sb, and Sc are 4, 5, and 3, respectively. Then, only Sa and Sb are feasible for the assignment. Next, if Sa and Sb have service/product quality (S.6) and functionality (S.8), their weighted unit impedances are 110 * (5/(4*2) + 5/(4*2)) = 137.5 and 120 * (5/(5*2) + 5/(3*2)) = 160, respectively (using the values shown below).

	S.2	S.6	S.8	weighted unit impedance
Sa	110	4	4	137.5
Sb	120	5	3	160.0

These weighted impedances are further adjusted according to the capability measures, i.e., Sa = 137.5/0.90 = 152.8 and Sb = 160/0.95 = 168.4.

Thus, the initial optimal impedance computation identifies the best choice of Sa for establishing the assignment to fulfill the target requirement. This process is applied to all requirements.

Dynamic Optimal Impedance Computation

An experiment covers a fixed number of cycles, whose duration varies according to the task being modeled. For some tasks the duration of a cycle might be a week or a month, but it could be longer or shorter. Inventory management in a large factory or in a high volume retail store might have a daily cycle, whereas a portfolio management service offered to individual banking or brokerage clients might have a monthly cycle time. In the first example discussed above, the cycle time is a semester; in the second it is a month.

At the end of each cycle in an experiment, a pseudo random number r in the interval [0, 1) is generated to determine whether or not the reference matrix will be modified. Data in the reference matrix are changed according to the following procedure:

(1) A requirement will be eliminated if the random number r is greater than or equal to the persistence value (R.3) of the requirement. For example, if some requirement has a persistence value 0.97 and the random number obtained is 0.98, then that requirement needs to be removed.

(2) Similarly, a satisfier may be eliminated if r is greater than or equal to the satisfier's longevity value (S.4). Note that each check requires a new random number drawing and that the elimination means setting the capability measure of the matrix's entry to 0.

Upon removing a requirement (in a rare circumstance), the impedance computed for that requirement is subtracted from the total impedance. (On the voSwitch 1.0 screen, the switching line will disappear, and the requirement box's color will be altered.) If any satisfier is removed, an alternative satisfier is assigned using the weighted unit impedance computation defined above, i.e., the best satisfier having the smallest weighted unit impedance among the remaining satisfiers is selected. The experiment is terminated if no satisfier is available for the requirement.

(3) The weighted unit impedance computed for every requirement and satisfier pair is adjusted to reflect an inflation rate (S.10) and a productivity efficiency (S.9) of the satisfier.

Using the example above, suppose that a satisfier Sa has the next set of attribute values and is currently assigned to some requirement. At time 0 (the beginning of the first cycle) the computed weighted unit impedance is 137.5. At time 1 (the beginning of the second cycle), the current inflation rate (S.10), 1% in the example, is used to increase the impedance value for the cycle. In addition, by drawing a random number that is larger than or equal to 4/5 = 0.8, a 2% decrease (S.9) of the weighted unit impedance is effected. Recall that the volatility (S.3) is an integer value between 1 and 5. The weighted unit impedance computation uses a linear combination of S.9 and S.10, i.e., (S.10 - S.9) is the weight used to express impedance fluctuations.

	S.3	**S.9**	**S.10**
Sa	4	0.02	0.01

The total impedance at time 0 is the 'initial switching impedance' plus the sum of all the smallest weighted unit impedances, each computed for a particular requirement and adjusted for the capability measure of the selected satisfier. The total impedance at time n is the initial switching impedance plus the sum of all the smallest 'adjusted' weighted unit impedances. Smallest 'adjusted' weighted unit impedance means the smallest impedance among the list of 'adjusted' weighted unit impedances.

The weighted unit impedance of each satisfier is altered in direct proportion to the inflation rate (S.10), and in inverse proportion to productivity (S.9) as the computation proceeds. Note that the adjustment of the weighted unit impedance must take place for every satisfier in the system whether or not it is selected for a particular assignment.

EXTENSION AND REFINEMENT OF THE SWITCHING MODEL

Further development of the model can be aided by experimenting with and modifying voSwitch 1.0. The aim of voSwitch software in general is to provide quantitative support for assessing the benefits and drawbacks of switching in comparison with traditional management approaches that treat the assignment of satisfiers to requirements as essentially fixed.

The evolving program could be used to explore the limits of the switching model. That is to say, a program derived from voSwitch 1.0 could serve as an instrument for establishing functional relationships between the benefits and drawbacks of virtual organization, and the conditions under which these relationships obtain. In particular, it should allow for determining:

1) Benefits taking account of the impedances and frequency of switching (i.e., number of switches per requirement per time interval) for fixed sets of requirements and satisfiers.
2) Benefits taking account of the frequency of changes in the set of satisfiers as well as of impedances and frequency of switching for a variable set of satisfiers.
3) Long-term benefits of virtual vs. conventional management for variable sets of requirements and satisfiers.

Useful benefit-drawback analysis hinges on realistic allocation and switching procedures. Further research needs to address these issues with a view to incorporating empirical findings in the switching model.

Allocation

The allocation procedure currently used by voSwitch 1.0 takes account only of contributions to the unit impedance of production in the determination of switching impedance. This approach calls for finding the satisfier(s) with minimal impedance, determining the impedance of switching (if such is contemplated) and using that information to decide whether or not switching would be justified. Note that satisfier attributes (e.g., volatility and longevity) could affect subsequent decisions about switching, so this procedure is not as simple minded as it might appear at first glance.

However, allocation procedures that take account of longevity, volatility, and perhaps other satisfier attributes could make the program more realistic. Qualitative factors such as good will, reputation, etc. could also be incorporated in the model if suitable quantitative measures could be devised. The allocation procedure assigns to each requirement the feasible satisfier of lowest impedance. As explained earlier, a satisfier is feasible for a requirement if the table shows it can be assigned to that requirement by a non-zero value that represents a given level of capability. In particular, if $S_1, S_2, \ldots, S_n$ are the feasible satisfiers for requirement R, and S_k is the one with the minimal unit impedance, then S_k is assigned to R. If there is more than one satisfier with the minimal unit impedance, one of these is chosen at random.

A 'diversification' option might give better results. That is to say, if a satisfier A has been assigned to requirement X, and satisfiers A and B are feasible for requirement Y, and in addition both A and B have the same minimal impedance among the feasible satisfiers for Y, then B should be assigned to Y. (This, for example, would tend to reduce excessive dependence on any one particular supplier.)

The mapping of requirements to satisfiers in the switching model is a many-to-many mapping. This generality in the model’s formulation is desirable since in practice a requirement may be met by several different satisfiers at the same time. Allocation of satisfiers to requirements in such a case must respect each satisfier’s limited capacity and must ensure that the needs of the requirement are fully met. These “capacities” of satisfiers and “needs” of requirements can be viewed as constraints in a linear programming application. A linear programming approach to allocation has been explored and implemented in a computer program (Elia, 2003). Subsequent versions of voSwitch will incorporate allocation methods that make use of linear programming and related methods to achieve a more realistic test of the switching concept.

Switching

At certain points in an execution of voSwitch 1.0, some of the weighted unit impedance of the unselected satisfiers may become smaller than that of the selected one due to the varying effects of the inflation rate and productivity measure and resulting fluctuation of the total impedance. In every execution period, immediately after completing the dynamic impedance computation described above, switching is considered by comparing the revised weighted unit impedance for all feasible satisfiers.

As noted earlier voSwitch 1.0 does not allow for the introduction of new satisfiers or requirements after the initial specification by the user. Clearly this is a limitation, one that does not adequately account for the dynamic character of tasks and marketplaces. It would be desirable, for example, to allow for the development of new computer science courses (i.e., new requirements) in the staffing model discussed above. This limitation could be overcome by incorporating in the program a probabilistic model for generating new satisfiers and requirements in the course of an execution. Possibilities for switching would then become more realistic.

Alternative switching regimes should be explored. Empirical research is needed to guide the identification of realistic attributes and values. In particular, voSwitch could be improved with the aid of experiments (such as the teacher assignment case discussed above) that compare computed outcomes with the observed results of switching in practice, pointing the way to needed adjustments in program parameters.

Guidelines for Management

The management of a virtually organized task can be resolved into five major responsibilities (Mowshowitz 1999):

1) analyzing abstract requirements;
2) identifying possible satisfiers;
3) switching and tracking allocations of satisfiers to requirement;
4) maintaining and possibly revising the procedure for allocating satisfiers to requirements;
5) reviewing and adjusting the optimality (or "satisficing") criteria of the allocation procedure. (The satisficing criteria defining the objectives of the allocation procedure are based on organizational goals. Given the strategic importance of such goals, it makes sense to separate the review of criteria from maintenance of the allocation procedure.)

Each one of these responsibilities should be examined with a view to making practical recommendations for the effective use of virtual organization. Such investigation should be guided by benefit-drawback analysis.

Responsibilities (1) and (2) call for dedication of resources in analytic and market scanning activities. The scope and thus impedance of these activities will vary with the type of virtually organized task (McKissick 1998). One research objective is to categorize such tasks according to demand for resources, and to determine upper bounds on levels of expenditure that could be justified on the basis of the potential gains of the switching approach to management.

Perhaps the most critical problem for a manager is deciding when to switch from one satisfier to another. If the relative impedances of alternative satisfiers were the only consideration, the decision could be relatively straightforward. The decision problem is complicated by the need to factor in the impedance-consequences of any potential switch. As indicated in the discussion of voSwitch 1.0, there are indirect as well as direct impedances associated with switching, and estimating them often requires data that are not readily available. The program should be used to develop switching guidelines for different categories of virtually organized tasks.

The process of reviewing and adjusting *satisficing* (Simon 1976) criteria also needs to be investigated. Empirical studies of virtual organization in action should be examined with a view to identifying best practices.

Virtual organization offers economic advantages over conventional approaches to management in a great variety of tasks. Electronic commerce, which can be expected to grow in tandem with Internet use, provides especially enticing opportunities for using the innovative management principles of virtual organization. In short, switching is not just a trendy new fashion in the business world. It is here to stay and is likely to become an ever more important instrument in the arsenal of management.

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AUTHORS

Abbe Mowshowitz has been professor of computer science at the City College of New York and member of the doctoral faculty at the Graduate Center of the City University of New York since 1984. In this period he has also held academic appointments at the University of Amsterdam (1994-1997, 1991-1993), Erasmus University Rotterdam (1990-1991), and the Rotterdam School of Management (2001-2002). Earlier he held academic appointments at Rensselaer Polytechnic Institute (1982-1984), the University of British Columbia (1969-1980), the University of Toronto (1968-1969), and the University of Michigan (1967-1968).

Mowshowitz began his research career in information theory and discrete mathematics, but shifted to organizational and social implications of computers some twenty-five years ago. He was awarded the 1990 Tinbergen Professorship at Erasmus University-Rotterdam in partial recognition of his work on computers and society. He has authored several books and reports, including *The Conquest of Will: Information Processing in Human Affairs* (1976), and many articles on the social implications of computing.

In recent years, his research has centered on virtual organization (an idea he conceived in the late 1970s). A book on this subject, *Virtual Organization: Toward a Theory of Societal Transformation Stimulated by Information Technology,* was published in 2002.

In addition to teaching and research, Mowshowitz has acted as consultant on the uses and impacts of information technology (especially computer networks) to a wide range of public and private organizations in North America and Europe. He received his PhD in Computer Science from the University of Michigan in 1967.

Akira Kawaguchi is an associate professor in the Department of Computer Science at the City College of New York. Before embarking on his academic career, he spent several years working in industry. He has held positions in Mitsubishi Heavy Industries, Bell Laboratories, AT&T Research Laboratories, and several startup companies. He received B.S and M.S. degrees in Administration Engineering from Keio University (Japan); and M.S. and PhD degrees in Computer Science from Columbia University.

Kawaguchi's current research interests lie in the areas of database and transaction processing systems, virtual organization, and information retrieval systems.