V.D. A Primer for a New Cross-Impact Language—KSIM

(*with Examples Shown from Transportation Policy)*

JULIUS KANE*

Editor's Note: *The understanding* of *the dynamics* of *complex systems for forecasting purposes has; been stressed in the pages* of *this Journal. Forrester's article and the review of his* World Dynamics *in recent issues attest to its importance. Professor Kane's article shows that the behavior of nonlinear feedback systems can be demonstrated without mathematical sophistication. It is, therefore,* of *particular value for pedagogical purposes and* for *communication with individuals who* do *not possess advanced mathematical training but must, nevertheless, be concerned with these problems.*

Abstract

A new methodology/language has been developed which serves to make available the workings of cross-impact analysis available to a much larger audience in that no technical sophistication is required to become expressive in the new language. Unlike the procedures developed by Gordon, *et al* our methods stress the structural dynamics of the system, the geometry of the linkages rather than refining arithmetic estimates of future probabilities. However, while qualitatively and subjectively oriented, our procedures can be easily expanded to any degree of precision, providing the data and mechanisms are sufficiently well known. The key feature of our approach is that it allows one to work with data of any level-from subjective estimates to highly precise physical measurements-and the computer has the character of logical projections of basic hypothesis rather than dogmatic imperatives which is the nature of much of present social, economic, technological, and ecological modelling.

---

* DR. KANE is Professor of Mathematical Ecology at the University of British Columbia, Vancouver, Canada.

Note: A reasonably complete bibliography of cross-impact analysis is given in Turoff's article in the first issue of *Technological Forecasting and Social Change, Vol. 3* (1972) and will not be repeated here.

Introduction

Realistic problems involve a multiplicity of competing variables, presenting a complexity of behavior that usually dwarfs human capacity for comprehension. Consequently decisions are usually made in truncated spaces by sharply reducing the variables that will be considered. It has been the consistent endeavor of systems scientists to develop models which have the capacity of enlarging the scope of human comprehension.

Because of their mathematical nature, most simulation models suffer from a variety of problems. For one they tend to be excessively numerical, concentrating attention upon those variables which can be readily quantified, and tend to exclude variables which while important are basically subjective in nature. For example, traffic flow and traffic capacity are relatively easy to measure and are usually included within the scope of all transportation models. However such subjective notions such as status, comfort, convenience, and freedom of access are seldom included within the analysis except perhaps as marginal perturbations. This is particularly unfortunate since often such subjective variables are the controlling parameters in the choice of transportation mode. Another shortcoming of most simulation models is that because of their highly technical nature they tend to inhibit policy makers from using them freely. Generally, simulation models are formulated and run by highly skilled "experts" with an elaborate and abstruse language. If anything, politicians are unlikely to read more than the abstract of the reports furnished by the "experts." As a result policy makers are denied the experience and intuition that *comes* with actual involvement with simulation models and thus tend to mistrust them. Thus *a* barrier is erected between those people who formulate and conceive simulation models and those who should ultimately use their output. It was the purpose *of* our research to try and design a simulation procedure -or better yet, a simulation language in which technically unsophisticated people could quickly become fluent *in* the logical expression of cross-impact concepts. In addition, the scope of this simulation language should be sufficiently powerful so that it would express the interaction of competing variables in a realistic and graphic fashion.

1. Aircraft Competition

The procedure we developed is simplicity itself. First, all the relevant variables are listed and given names. For example, in an aircraft interaction model, these might be:

SST: for the supersonic transport,
B747: for the Boeing jumbo jet and other large capacity aircraft of similar type,
JET: for conventional jets of the DC8/B707 variety,
STOL: for short take-off and landing planes,
VTOL: for vertical take-off aircraft, such as helicopters,
HSG: for high speed ground transportation, typically of the monorail variety, and
CM: for cost of money

It is immediately evident that these variables interact strongly with one another. In some cases they compete directly, for example, the SST and *B747* are in large part competitive. On the other hand, they *also* form alliances, for example, development of high speed ground transportation will probably be a big plus for the development of the SST because this would provide high speed rail links that could service a supersonic jetport located remote from urban regions.

To a first approximation the interactions can be simply summarized by a table of the following form (Table 1).

Table 1

Interaction Matrix of Transportation Modes[a]

Impact	SST	B 747	JET	STOL	VTOL	HSG	CM	INTERVENTION
SST	+	----	--	+	0	+	---	0
B 747	-	+	++	++	+	+	---	0
JET	--	----	-	-	0	-	0	0
STOL	++	+++	++	+	--	0	-	0
VTOL	+	+	+	--	+	-	-	0
HSG	+	+	0	--	--	+	--	++
CM	0	0	0	0	0	0	0	0

[a] **Note that the *impact is column heading upon row entry*. Thus the impact of *JET* upon *B 747* = +2 while the impact of *B 747* upon *JET* is −4.**

This matrix summarizes the interactions between the variables in the following fashion. At each location we enter the action of the column heading upon the row heading. A plus entry indicates that the action of variable A upon variable *B* is positive. In other words A encourages *B's* growth and that such encouragement will be proportional to both the relative size of A and the magnitude of the interaction coefficient (not necessarily integer values). We have chosen most diagonal entries to be positive in accord with the idea that technology tends to foster its own growth. The sole exception is the self-interaction of *JET* which we have set as minus. This is to suggest that this variable has reached a stage of obsolescence in its evolution.

There is an extremely important pedagogical value in choosing the matrix entries as combinations of pluses and minuses rather than numerical entries. By not asking for numerical coefficients at the outset psychological barriers are greatly reduced, stimulating group participation and discussion. Furthermore *subjective* variables can very easily be introduced and there is no inhibition in making them plays their proper role. Of course ultimately the pluses and minuses are translated into specific figures.

Note that the entries in the interaction matrix are not necessarily symmetric, the action of A upon B is not usually the same as *B* upon A. For example we note that JET upon *B747* = +2 while the impact of B747 upon JET is -4. The strength and direction of the interaction can easily be adjusted by varying the appropriate interaction coefficient. In the matrix of interactions we have also added another column (temporarily blank), which is reserved for the action of the outside world. These are variables (say governmental intervention), which act upon the system but experience essentially no reaction in turn. This is a very convenient and important feature.

It is the nature of all variables encountered in human experience to be bounded. Invariably there is a minimum below which the variable cannot descend, and at the other extreme there is a maximum beyond which it cannot penetrate. With. This in mind we can always scale the range of each of our variables between zero and one. For example, for an aircraft variable a value marginally above zero might indicate the raw conception of the vehicle, and at the other extreme, a value approximating unity would correspond to complete commercial success. With such a scaling in mind we could assign the following values for the present configuration:

SST = 0.2 because the vehicle has entered prototype phase but neither the Concorde or Tu-144 have been commercially introduced,
B747 = *0.35* because it has entered commercial service but not yet in appreciable quantity,
JET = 0.8 because this has entered commercial service in very significant numbers and is a proven yet not overwhelming financial success owing to the large numbers of competing aircraft,
STOL = 0.15 because while this has been tested in research models no viable commercial prototypes have yet appeared,
VTOL = 0.1 since VTOL shares all of the technical problems of STOL yet more so,
HSG = 0.1 because it is barely beyond the prototype phase and suffers from a multitude of operational problems.
CM = 0.9 inasmuch as the cost of money is hovering at historically high levels.

It will be noticed that both the entries and the interaction matrix and the initial values of the variables are somewhat arbitrary. There is considerable room for disagreement. For example, it would be easy to argue that high-speed ground transportation should be assigned an initial value of 0.2 rather than 0.1. Likewise it could be argued that the action of the SST upon itself is negative rather than positive owing to the unfavorable publicity is has received. The ease of the model's formulation allows such contrary views to be, expressed easily and in a self-consistent fashion. Often it will be found that the particular choice of a single interaction parameter is not terribly important. Our rationale is' to give the policy maker free choice in designing his model without being burdened by mathematical and computational complexity. In other words, each policy-maker can change his conception of the structure of the system freely as his intuition into its behavior improves.

But once a particular interaction matrix and initial values have been chosen, then the future is set, continuously evolving from the initial configuration. The actual mathematics that achieves this goal is outlined in the appendix and will be discussed at length in a technical paper. Here, it suffices to say that each interaction is weighted proportionately to the strength of the interaction and also to the relative size of the variable producing the interaction. Also, and most important, growth and decay follow logistic type growth variations rather than exponential ones, *automatically limiting reaction rates near threshold and saturation.* In a completely self-consis tent way then the system will evolve from knowledge of the binary interaction of its components.

MATHEMATICAL ASIDE (Can be omitted at first reading.)

The mathematical calculations are carried out on an iterative basis, avoiding the need for any explicit discussion of differential equations. To construct our model, we employ a simulation language *(KSIM)* with the following properties:

(1) System variables are bounded. It is now widely recognized that any variable of human significance cannot increase indefinitely. There, must be distinct limits. In' an appropriate set of units these can always be set to one and zero.
(2) A variable increases or decreases according to whether the net impact of the other variables is positive or negative.
(3) A variable's response to a given impact decreases to zero as that variable approaches its upper or lower bound. It is generally found that bounded growth and decay processes exhibit this sigmoidal character.
(4) All other things being equal, a variable will produce greater impact on the system as it grows larger.
(5) Complex interactions are described by a looped network of binary interactions.

With these conditions in mind consider the following mathematical structure. Since state variables are bounded above and below, they can be rescaled to the range zero to one. Thus for each variable we have

$$0 < x_i(t) < 1, \qquad \text{for all} \quad i = 1, 2, ..., N \text{ and all } t>0. \tag{1}$$

To preserve boundedness, $x_i(t + ?t)$ is calculated by the transformation

$$x_i(t+\Delta t) = x_i(t)^{p_i} \tag{2}$$

where the exponent $p_i(t)$ is given by

$$p_i(t) = \frac{1 + \frac{\Delta t}{2} \sum_{j=1}^{N} (|\alpha_{ij}| - \alpha_{ij}) x_j}{1 + \frac{\Delta t}{2} \sum_{j=1}^{N} (|\alpha_{ij}| + \alpha_{ij}) x_j}, \tag{3}$$

where a_{ij} are matrix elements giving the impact of x_j on x_i and ?t is the time period of one iteration.

Equation (3) guarantees that $p_i(t) > 0$ for all i = 1; 2, . . ., N and all t = 0. Thus the transformation (2) maps the open interval (0, 1) onto itself, preserving boundedness of the state variables (condition 1 above). Equation (3) can be made somewhat clearer if we write it in the following form:

$$p_i(t) = \frac{1 + \Delta t\,|\text{sum of negative impacts on } x_i|}{1 + \Delta t\,|\text{sum of positive impacts on } x_i|} \tag{4}$$

When the negative impacts are' greater than the positive ones, $p_i > 1$ and x decreases; while if the negative impacts are less than the positive ones, $p_i < 1$ and x increases. Finally, when the negative and positive impacts are equal, $p_i = 1$ and x_i remains constant. Thus the second condition holds. To demonstrate conditions 3-5 let us first observe that for small ?t, Eqs. (2) and (3) describe the solution of the following differential equation:

$$\frac{dx_i}{dt} = -\sum_{j=1}^{N} a_{ij} x_i x_j \ln x_i \tag{5}$$

From Eq. (5) it is clear that as x_i? 0 or 1, then dx_i/dt? 0 (condition 3). Thus, the expression $x_i \ln(x_i)$ may be said to modulate the response of variable x_i to the impact it received from x_j. Considering x_j individually, we see that as it increases or decreases the magnitude of the impact of x_j upon any x_i increases or decreases (condition 4). Finally, it is seen that condition (5) holds since system behavior is modeled, through the coefficients a_{ij}, each of which describes the binary interaction of x_j upon x_i. Although the previous discussion seems to imply that the impact coefficients are constants, this need not be so. In more advanced versions of KSIM any of these coefficients may be a function of the state variables and time.

To gain a greater intuitive understanding of this system of equations it is a worthwhile exercise to examine the one-variable system. The reader can easily check that in this simple case the system exhibits sigmoidal-type growth or decay corresponding to a positive or negative. Such growth and decay patterns are characteristic of many economic, technological, and biological processes.

DISCUSSION

Figure 1 shows the subsequent evolution of the variables from the assumed initial values. It will be noted that with the supposed interactions that B747 and STOL have the brightest future whereas HSG and the SST are quickly driven to extinction. In other words, they just can't compete' with alternate forms of transport.

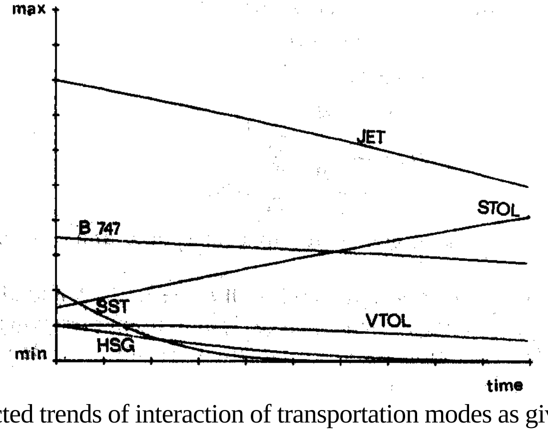

Fig. 1. Projected trends of interaction of transportation modes as given by Table 1.

The aircraft model suggests a number of very interesting intervention schemes. Figure 2 indicates the result of truly massive (and unrealistic) intervention of the federalgovernment on HSG sufficient to reverse on the rest of the system except that the growth rate of jumbo jets, B747, are slightly enhanced, while JET and VTOL receive an adverse experience. (The dashed lines indicate their former positions in Fig. 1.)

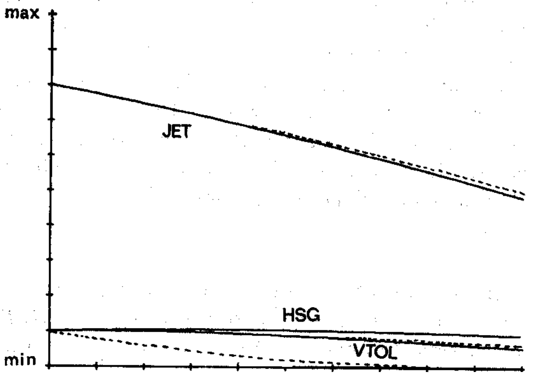

Fig. 2. Massive federal intervention on behalf of HSG produces slight declines in JET and VTOL. (Dashed lines indicate the old trends.) B747 prospects are slightly enhanced but too small to be indicated. There is no significant change in the other variables.

We are considering much more refined versions of the present analysis including such important *effects* as environmental present analysis including such important variables as El, environmental impact. These we are considering separately in a more sophisticated format, for example aircraft variables will be calibrated by the actual share of the market rather than subjective estimates. This work will appear separately together with a more elaborate version of the cross-impact language. In addition we are considering models which reveal social and economic consequences of various transportation policies. Owing to the large number of variables in such models it will be much easier to communicate the nature of our work by describing a much simpler model, one related to transportation planning in the greater Vancouver region. Namely, let us consider the possibility of diverting significant traffic away from the automobile and towards rapid transit. As an explicit question may we ask, "Can massive funding of public transit achieve its goal of easy metropolitan access?"

II. A Metropolitan Transit Model

To answer this question we must consider not only economic factors but also subjective considerations, for example the freedom that comes with caruse (immediate availability, multiplicity of route choices, and easy diversion to alternate destinations). In public transit one is locked to timetables, rigid routing, and limited accessibility to destinations. Clearly *FREEDOM* should be a variable. We shall also include USE (for the relative fraction *auto* use), C&C for comfort and convenience, COST, and *SPEED*. In detail we define the variables in the following fashion:

1. COST[1]: This variable is scaled between zero and one and essentially measures the perceived cost of the automobile as a fraction of the total annual income of the individual. Consequently, an individual making $10,000 a year roughly figures (in his head) the automobile is costing him a thousand dollars per year-whether right or wrong would have a value for this variable of 0.1.

2. USE: This is to be described as the use of the automobile as a transportation medium as compared to all competing means of transportation therefore a value of 0.95 of this variable indicates that the automobile is used 95% of the time as against all possible modes such as public transportation (buses, etc.) or walking.

3. C&C: Comfort and convenience and all other attributes of aesthetic desirability. We choose C&C to be zero when the use of the *automobile* is accompanied by acute discomfort. When C&C = 1 use of the automobile is with total satisfaction and luxury.

4. FREEDOM: This variable essentially measures the freedom of choice involved in travel. It includes such considerations as choice of alternate routes and restructuring of schedules to meet new situations as they occur. It will be obvious that the automobile -which is ready at almost a moment's notice-should have this particular variable set to values which are close to unity.

5. *SPEED:* This variable measures the *perceived* automobile speed between any two random points within the transportation net. Unity is described as the speed between two points under ideal circumstances-maximum speed and no traffic. During the day its value would be something like 0.9 for an automobile except during rush hours when it might drop as low as 0.7 or 0.6.

DISCUSSION OF MATRIX ENTRIES

In the transit model under discussion we have introduced five variables, which interact with each other. In addition, there is always the outside world acting upon these variables for an additional five interactions. Accordingly there are five self-interactions, twenty binary interactions, and five external intrusions. Choosing these thirty parameters will define the system. A reasonable first approximation is given in Table *2*.

Let us write A : B for the action of A upon B and then we can describe our motivation for the above choices as follows.

AUTO USE: COST (--). We argue that increased auto use diminishes *perceived* cost. Our rationale for this choice is that the costs of the automobile are largely implicit, most notably depreciation. For most people the major expense of having a car is consigned to the past, i.e. the date the car was purchased. Accordingly, the attitude of

---

[1] Note. We have run many versions with two cost variables, differentiating between direct operating costs (gas, oil....) and implicit overhead costs (depreciation, insurance....). The conclusions of such more refined approaches do not differ in any significant regard from the ones to be presented.

Table 2
An Interaction Matrix Describing the Present Pattern of Public/Private Transportation

Impact	COST	AUTO USE	C & C	FREEDOM	SPEED	OUTSIDE WORLD
COST	0	--	++	+	+	-
USE	++	+	++	++	++	+
C & C	+	--	0	0	0	+
FREE	+	---	0	0	0	++
SPEED	+	---	0	+	0	++

most is that a car standing idle in the garage represents an expense without any concomitant service. Thus people tend to use their car as a means of psychologically amortizing their high investment. This is in sharp contrast to the use of public transit where toll costs are highly explicit in nature. Whenever an individual uses the bus he is acutely reminded of its cost when he reaches into his pocket for a coin.

C&C: COST (++). Obviously the more luxurious a car, the more it will cost.

FREEDOM: COST (+). Clearly freedom exacts a price. For example increased reliability come with either better automobiles or better service and maintenance.

SPEED: COST (+). Faster and more maneuverable cars generally cost more.

OUTSIDE WORLD: COST (-). Owing to technological advances and productivity gains, the *relative* cost of a car has been declining consistently for about forty years. The costs of car ownership have risen significantly less than wage rates or general inflation.

COST: USE (++). The more expensive a car the more anxious the individual will be to use it and to display his prized possession.

USE: USE (+). Use encourages more use and tends to be habit forming.

C&C: USE (++). The more comfortable and convenient he car (especially in contrast to mass transportation), the more its use will be encouraged.

FREEDOM: USE (++). The easier a car's access to arbitrary destinations the more its use will be encouraged.

SPEED: USE (++). The greater the relative speed of the car as compared to public transit the more it will be used.

OUTSIDE WORLD: USE (+). The outside world encourages the use of the automobile because the automobile is a much higher status mode of transport than public transit.

COST: C&C (+). The more a car costs in general, the more its comfort and convenience.

AUTO USE: C&C (--). Clearly the more an automobile is used the less comfortable it will tend to be owing to mechanical deterioration as well as increased road congestion.

OUTSIDE WORLD:C&C (+). The outside world tends to encourage automotive comfort and convenience by virtue of freeway construction and other traffic engineering.

COST. FREEDOM (+). A brand new car will be more reliable than an old clunker. In general, we can expect that the more the cost the greater the freedom from service problems.

AUTO USE:FREEDOM (-). This is sharply negative because increasing auto use markedly increases traffic congestion which sharply diminishes freedom.

OUTSIDE WORLD:FREEDOM (++).. The outside world will generally build freeways and provide alternate routing as traffic mounts, thus tending to restore freedom.

COST: SPEED (+). Jaguars can go faster than Volkswagens.

AUTO USE: SPEED (---). Auto use sharply inhibits speed because of increasing traffic congestion.

FREEDOM: SPEED (+). This is taken as a positive factor because the more choices an individual has in reaching his destination the higher his average speed can be. A car can choose an alternate route where a bus might be stalled in traffic.

OUTSIDE WORLD: SPEED (++). Again, because of the government's predilection to build freeways, it continuously encourages greater speed.

As initial values we choose:

AUTO USE	= 0.8
C&C	= 0.6
FREEDOM	= 0.6
SPEED	= 0.5
COST	= 0.2

These choices are not_ representative of the present situation and have deliberately chosen to handicap auto USE. It will be seen that the handicap is but a fleeting burden.

DISCUSSION OF COMPUTER OUTPUT

Once the initial values and the matrix of interactions have been agreed upon it is a simple procedure by our methods to project the future states of the system. Figure 3 illustrates the subsequent behavior that would emerge from our assumptions.

It will be seen that variable *2, AUTO USE,* rises continuously until it reaches maximum. This is in spite of a slow but steady decline in comfort and convenience, freedom, and speed. If this is surprising then we must remember that as comfort, freedom, and speed decline, auto use begins to decline but this results in a decreased traffic congestion which ultimately encourages a net increase in AUTO USE. (An easy illustration of counter-intuitive behavior).

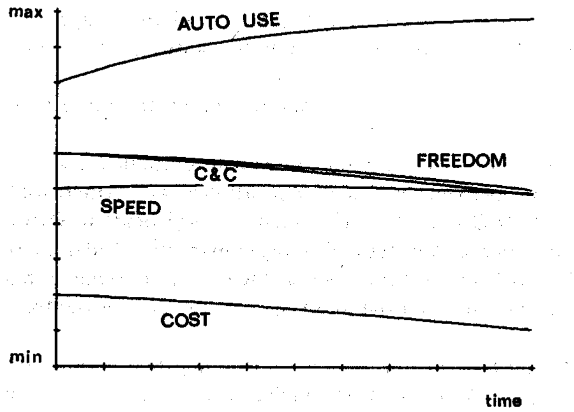

Fig. 3: Projected trends as set by the impact matrix given in Table 2.

The behavior of the system cannot really be fully understood until a number of intervention strategies have been suggested and pursued to their conclusion. However any realistic manipulation will produce a barely perceptible effect. This stems from the intrinsic stable behavior of multiply-interacting systems. Even in our relatively naive model there are 21 nontrivial interactions and this complexity endows the system with a stubborn resistance to change. This of course is well known to ecologists (and some politicians) but the importance of this knowledge cannot be overstated. To illustrate the resistance to change we consider some extreme disruptions of the system.

TAX THE CAR TO DEATH?

In the next run we have made an extreme external perturbation, supposing that the outside world markedly increased the cost of the car instead of reducing it over time as before. We go to an extreme, making 0 W. COST =+9, rather than -1. As we can see from Fig. 4, COST instead of diminishing rises sharply to maximum. However, automobile *USE* still rises to saturation except that *its* rate of increase is no longer as sharp as it was in Fig. 3. It will also be noted that C&C and *FREEDOM* still decline. However *SPEED* now rises, slowly to be sure but significantly. This is largely a result of decreased congestion.

HOW ABOUT HALTING FREEWAY CONSTRUCTION?

For our next run we have restored the original values in the interaction matrix and have made the following changes: The intervention of the outside world upon *FREEDOM* and *SPEED* instead of being doubly positive would be doubly negative. This would correspond to a strategy diverting funds from freeway construction to the construction of rapid transit. It will be seen (Fig. S) that freedom and speed now decline rather sharply as well as comfort. However, despite these inhibitions auto USE, continues to rise to its saturation value.

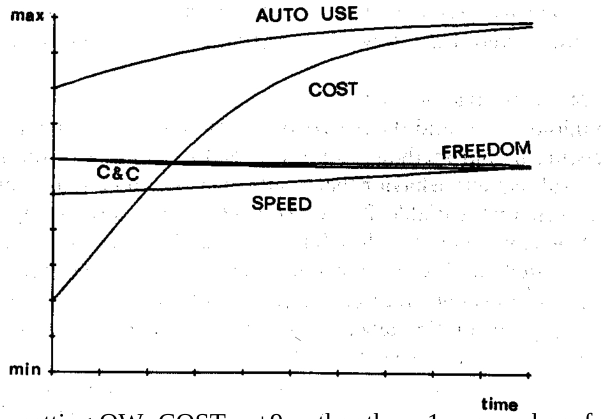

Fig. 4. By setting OW: COST = +9, rather than -1, we are hopefully "taxing the car to death." As can be seen, it manages to survive.

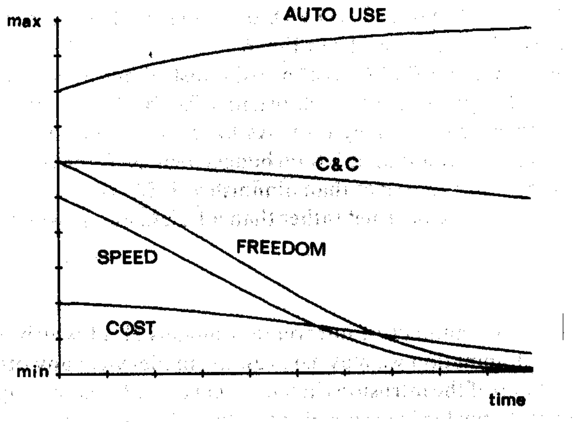

Fig. 5. Reversing freeway construction can be modeled by setting O*W:FREEDOM* = -2 and OW: *SPEED* = -2 instead of their former positive values. Even so, AUTO USE continues to rise.

DIVERTING FUNDS?

We now consider a different strategy, one of attempting to use negative feedback. In other words making the cost of the car tend to subsidize its opposite, public transit. This is achieved in the following way. Previously the impact of cost upon freedom and speed had been positive, in other words, man could buy more freedom and speed by spending more money. Now we reverse the situation and tax him proportionately in accordance with *FREEDOM* and *SPEED*, diverting funds to improve rapid transit. Making the indicated changes results in Fig. 6.

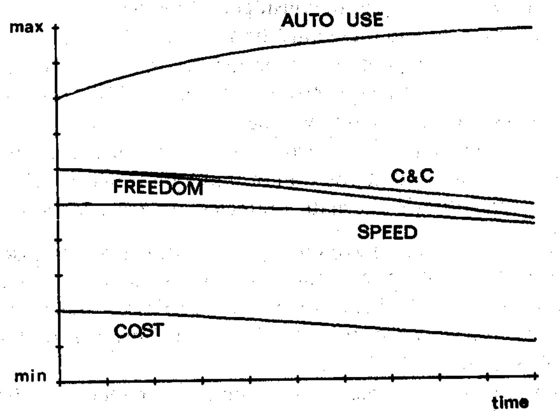

Fig. 6. Diversion of funds is introduced by setting COST: *SPEED = -1* and *COST:FREEDOM = -1.*

As can be seen, C&C and *FREEDOM* are diminished but none the less AUTO USE continues to go up. The problem is that the negative feedback is linked through a variable which itself is rather small, namely cost. As long as the automobile occupies only ten or twenty percent of an individual's total budget increasing the cost of the automobile will be absorbed by other strategies than diminished USE. For example, the individual might be forced to drive a Chevrolet rather than a Buick, but he will doggedly continue to drive.

ANY HOPE?

Having considered a number of intervention models all of which implies the automobile's ultimate domination we may ask, can the model yield any other answer? The answer is yes, but only if the intrusions in the system are extremely strong and powerful, or a magnitude probably far in excess of that which the voting public would be willing to endure. What we are working against is the following linkage: In Table 2 the impacts A UTO *USE: FREEDOM* = -3 and A *UTO USE: SPEED* = *-3* (congestion) serve to inhibit auto use. What seems to be a paradox, but is a typical example of the perverse behavior of looped systems, is that *almost anything we do to diminish AUTO USE makes A UTO USE more attractive because it decreases congestion.*

Conclusions

Certainly the naive models just considered are hardly conclusive. No, doubt many readers will be infuriated, arguing for different choice of initial conditions or interactions. But this is just what we have sought, i.e., controversy and interaction. But also

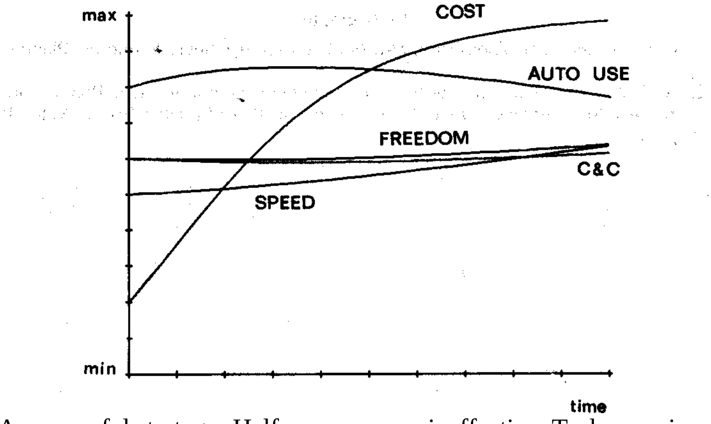

Fig. 7. A successful strategy: Half measures are ineffective. Truly massive cost increases are required, OW:COST= +9 and COST:USE =-9. Note even so that AUTO USE maintains its initial rise and then declines but slowly.

we have introduced a single and graphic model that any one can use, be they politician or citizen's action group. No mathematical or systems training is required. What is needed is the discipline to carefully consider all the interactions. Any one using the model must fill in all the matrix entries. Whatever his choice, we have found more often than not he will be hoist by his own petard. So often the system will either fail to respond or respond in an entirely perverse manner. What we want to communicate are two messages

(1) *COMPLETENESS.* The need to consider *all* interactions. If we have *n* variables then there are *n2* interactions and these must be accounted for. Using purely qualitative considerations it is very easy to omit, forget, or underestimate significant interactions.

(2) The *STABILITY* that emerges from *COMPLEXITY.* The more interlocked variables the more resistant the system will be to arbitrary change. Thus, in a time of social upheaval, an elementary but reasonably comprehensive means of communicating, "Beware what you do, that you do not undo yourselves," is obviously needed, particularly if the model allows alternate strategies to be easily simulated.

A strategy that will work is to have the outside world strongly raise the cost of the automobile *(OW:COST=+9)* and at the same time to divert that cost to inhibiting auto use *(COST:USE = -9).* If this is done, the COST rises sharply as can be seen in Fig. 7 and *USE,* begins a slow but steady decline. Note however, that with this decline in *USE* that C&C and *SPEED* all rise.

In this presentation we have tried to communicate a conclusion that continuously emerges in working with simulation models: *The structure of the system* (the nature of its interactions) is *far more important than the state of the system.* Any artificial increment of a variable is usually immediately dissipated unless concomitant structural changes are made. What is most important are the *linkages of* any variable to the other variables of the system. A major objective in devising our model is to communicate the overriding importance of *structure rather than state* to policy makers. As Jay Forrester has pointed out in a number *of* books, notably *Industrial Dynamics* and *Urban Dynamics (MIT* Press) interventions in complex systems often lead to results which are entirely at odds with the initial expectations. Any complex system defines an integrity of its own and strongly resists external changes, a fact well understood by ecologists. When complex systems change they seldom change continuously but rather flip suddenly into an entirely new configuration. These subjective conclusions can be made precise through the associated mathematics, and this will be the subject of a number of papers.

Extensions

In other papers (Kane, Vertinsky, and Thompson) we discuss the following elaborations of our language.

1. CALIBRATION. While the model easily accepts qualitative inputs, more precise methods of arriving at cross-impact parameters are needed. We are considering techniques based upon multiple correlation and the "Delphi method."

2. HIGHER-ORDER SIMULATION MODELS. For greater realism we have begun consideration of cascaded models of the variety described. This permits the interactions themselves to be functions *of* the state of the system. Clearly A need not always be B's friend. A's attitude towards B can be conditional on the relative status of their difference A - B or perhaps depend upon the state of a third individual C.

Perhaps much more important is the following refinement. Often we sense not a variable but rather *changes in a variable.* Our response to environment has much this character. Whether our. locale is good or bad we quickly become acclimatized: to it and then become sensitive only to gross changes. Such derivative interaction is very important and is the subject of other papers (Kane, Vertinsky, and Thompson).

Bibliography

J. Kane, 1. Vertinsky, and Wm. Thompson, *Health Care Delivery, Socio* Economic Planning Sciences (in press).[†]

J. Kane, 1. Vertinsky, and Wm. Thompson, "Environmental Simulation and Policy Formulation", *Proc. International Symposium on Modelling Techniques in Water Systems, Vol. 1, A. K. Biswas,* Fd., Ottawa (1972).

[†] 6 (1972) pp.283-293