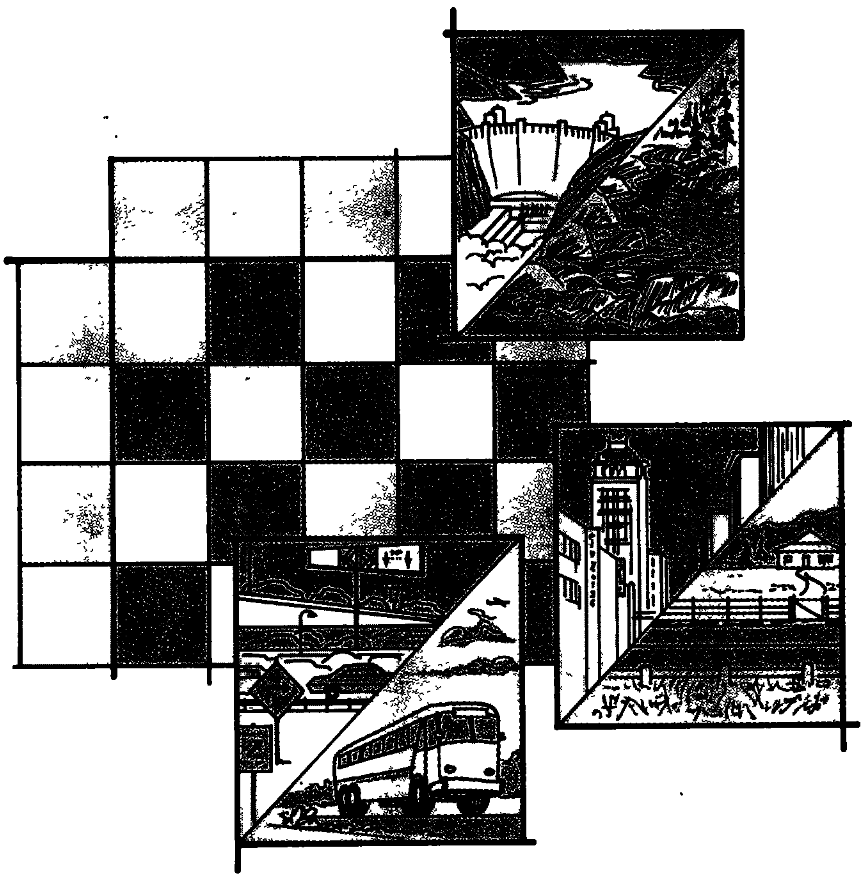
CROSS-IMPACT SIMULATION IN WATER RESOURCE PLANNING

NOVEMBER 1974

A Report Submitted to the:
U.S. Army Engineer Institute for Water Resources
Kingman Building
Fort Belvoir, Virginia 22060



By

Stanford Research Institute
Menlo Park, California

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This report describes a planning procedure known as KSIM for structuring and analyzing relationships among broadly defined variables in large socio-economic systems. The procedure enables a team of planners, first, to define and structure a set of variables describing a perceived problem and then, using a computer, to calculate and display the changes in the variables over time. By observing the changes and then making modifications and refinements, the team

developed a model of the problem situation. With a model planners can test various alternatives and review and improve their understanding of the problem. An example is included in the presentation.

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INTRODUCTION

Recent legislation and administrative orders have broadened the scope of planning for federal and federally-assisted water resource planning activities.

These directives contain two important consequences for water resource planners:

- First, the scope of concern or context of planning has expanded to include many new considerations, viewpoints, and variables. This has significantly *increased the complexity of planning.*
- Second, the emerging policy embodied in the legislation indicates that planning, in addition to dealing with complex current situations, must explicitly introduce *consideration of the long-term consequences* of proposed actions.

To consider long-range changes in complex situations, the interaction over time of significant planning variables must be identified, traced, and studied. KSIM, the procedure described in this report, provides a convenient method to meet these new and expanded planning requirements with special emphasis on forecasting and future-oriented methodology. Specifically, KSIM aids water resource planners in identifying problems, formulating alternatives, and assessing the impacts and long-term consequences of those alternatives.

Following a description of KSIM, the report gives an example of its application to a water resources planning problem. Concluding the report is a discussion of the outlook for future use of KSIM by water resource planners. The appendix contains a brief description of KSIM assumptions and mathematical formulation.

KSIM – A CROSS-IMPACT SIMULATION

What is KSIM?

KSIM is a simulation procedure for structuring and analyzing relationships among broadly defined variables in large socioeconomic systems. It was originally developed by Dr. Julius Kane, University of British Columbia, to allow decision makers to (1) accommodate a mix of hard data and intuitive judgment and (2) test alternative planning options efficiently by:

- Exploring how a range of likely futures may

Table 1 – TERMS USED IN THIS REPORT

Alpha values. The constant (long-term) relationship between two variables.

Beta values. The rate of change (short-term) relationship between two variables.

Cross-impact. The binary interaction between variables.

Cross-impact matrix. A table of variables in columns and rows that describe the interactions between the column and row variables.

Exogenous variable. A variable that is assumed to be outside and independent of the system.

Effects (impacts). Changes expected to occur in response to specific resource management measures. The term "effects" is synonymous with impacts (U.S. Dept. of the Army, Draft ER 1105-2-200).

KSIM. A procedure for analyzing a complex system by identifying how critical relationships among system variables determine the behavior of the system.

Model. An abstraction from or a simplification of the real world that attempts to focus on key variables and their relationships.

On line. Refers to time-sharing access to computerized information, such as data, programs, and models.

Outside world. For purposes of KSIM analysis, it is an exogenous variable that acts on the system but is not acted upon.

Procedure. A series of steps followed in a regular orderly definite way.

System. An array of related principles or parts given coherence by focusing on the achievement of an object.

Simulation. The technique of analyzing problems by following the changes over time of a dynamic model of a system.

Time sharing. Shared use of computers by several users from remote terminals.

Variable. Anything that is able or apt to change.

CHANGING REQUIREMENTS FOR WATER RESOURCE PLANNING

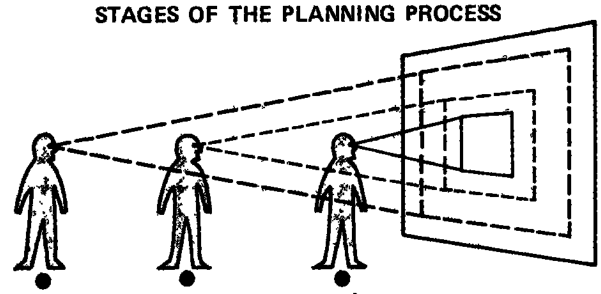
These recent legislative and administrative requirements affect water resource planning for federal and federally-assisted water activities:

- National Environmental Policy Act, 1969, Public Law 91-190
- River and Harbor and Flood Control Act, 1970, Public Law 91-611
- Water and Related Land Resources, Establishment of Principles and Standards for Planning, 1973, Water Resources Council
- Water Resources Development Act, 1974, Public Law 93-251
- Planning Process: Implementation of Principles and Standards and Other Related Requirements, May 1974 Draft, Corps of Engineers.

The purpose of these new requirements is to accomplish a national policy that considers the interaction of all aspects of a federal program upon the physical and socioeconomic environments and to plan for their enhancement. Water resource projects of the Corps of Engineers programs must be planned and evaluated in a much broader and more complex context than previously. Environmental, social and economic *impacts* must be considered, and, the outcome of these must be traced to identify long-term higher-order impacts.

The added complexity of resource problems suggests that the planning process be structured in several stages of increasing levels of detail. The early stage of planning must consider the widest possible range of concerns at a very general level of detail while final stages can focus on very precise design configurations. This should allow an early identification of critical issues that can be addressed more specifically by the project design. To treat the long-range considerations of complex situations, changes in the interactions of important planning variables over time must be identified, traced, and studied. Advanced long-range planning procedures are needed at each stage to meet these difficult and challenging tasks effectively.

STAGES OF THE PLANNING PROCESS



Broad Scope — A Set of Planning Objectives

Intermediate Plan Development — A Range of Alternative Ways of Achieving the Objectives

Detailed Plan — An Array of Feasibility Plans

A Complete Message is Available at Each Stage in Terms of:

- Problem Identification
- Alternatives Formulated
- Impacts Assessed
- Evaluation

FORECASTING PROCEDURES

Planning Stage	Problem* Characteristics	Forecasting* Techniques	Corps Application
1. Broad Scope	Definable Defined objective Mixed analytical and experimental	Cross-Impact (KSIM) Morphological analysis Scenarios Normative forecasting	Early stage Problem identification Assessment and evaluation
2. Intermediate Plan Development	Defined Experimental	Regression Analysis Consensus Delphi Trend Extrapolation Input-Output Tables	Well-structured problem with strong consensus such as flood plain hydrology
3. Detailed Plan	Well defined Analytical	Simulation, modeling Correlation analysis Substitution analysis	Simulation of waste water treatment plant

*Source: Ian I. Mitroff and Murry Turoff, "The Whys Behind the Hows," 1973.

shape a plan or, in turn, be subsequently modified by a plan

• Examining how various changes, such as in public preference, could affect plans.

The procedure enables a team of planners, first, to define and structure a set of variables describing a perceived problem and then, using a computer, to calculate and display the changes in the variables over time. By observing the changes and then making modifications and refinements, the team develops a model of the problem situation. With a model, planners can test various alternatives and review and improve their understanding of the problem.

Corps planners can use KSIM to study the implications of changes that can result from the interaction of system variables or from implementation of an alternative solution for water resource planning. It can also be an effective procedure for incorporating community participation into water resources planning. The simulation does not tell planners what alternative solution to choose. Rather, it is an information and display device by which major issues, needs and concerns emerge.

Attention is focused on the interrelated aspects of a planning problem. The procedure facilitates communication among planners and other specialists with different backgrounds. It enables them to address a problem from many different perspectives by increasing sensitivity to contrasting viewpoints in effecting a team consensus. In the process, participants deepen their understanding of the problem and thereby improve their ability to plan for the future.

Specifically, KSIM is designed to:

• Assist a team of people with diverse backgrounds to structure a problem on a broader basis than that available to one individual

• Formulate alternatives and assess consequences quickly, so that many relevant and imaginative alternatives can be evaluated

• Incorporate experience and subjective knowledge of individuals as well as selected statistical data in situations involving complex environmental and social parameters and engineering constraints

• Provide a systematic procedure to document and summarize the activities of the team. KSIM can be a means of establishing the scope of study for more detailed planning as well as outlining issues for further dialogue with community interest groups and technical specialists.

INTUITION . . . JUDGEMENT . . . KNOWLEDGE . . . CERTAINTY

"We have an extensive vocabulary enabling us to describe situations with varying degrees of precision. The difference between knowledge and intuition is not that one is rational and the other emotional, but rather the degree of assurance we have in the 'truth' of the assertions. Loosely speaking, we term *knowledge* those bits of data whose truth can be established with the probability greater than 0.8; whereas, we use *intuition* to describe things we sense to be true.

"The problem we face in environmental simulation is doing justice to all pieces of information, accepting them for what they are with all their limitations, rather than rejecting them simply because they lack the reliable format of what the physical scientist calls 'hard data.' It is 'soft data' – value judgments, opinions, cherished notions – which control the dynamics of human systems. If computer models are to be effective instruments of public policy, then they must have open channels which can accept such subjective data and give it its proper role."

Julius Kane

"On the one hand, we are faced with a lack of data to which we can attach truth or knowledge claims when making policy or planning goals, and on the other, we are faced with goals that are themselves reflectors of beliefs – beliefs that need not necessarily carry with them a condition of truth."

Stuart A. Sandow

"Reliable prediction of the future is impossible, so the planner who must decide in terms of the future must fall back upon projections illustrative of what the real future may be like. Moreover he must appreciate several different versions of the future or else pretend that he knows which one will come to pass.

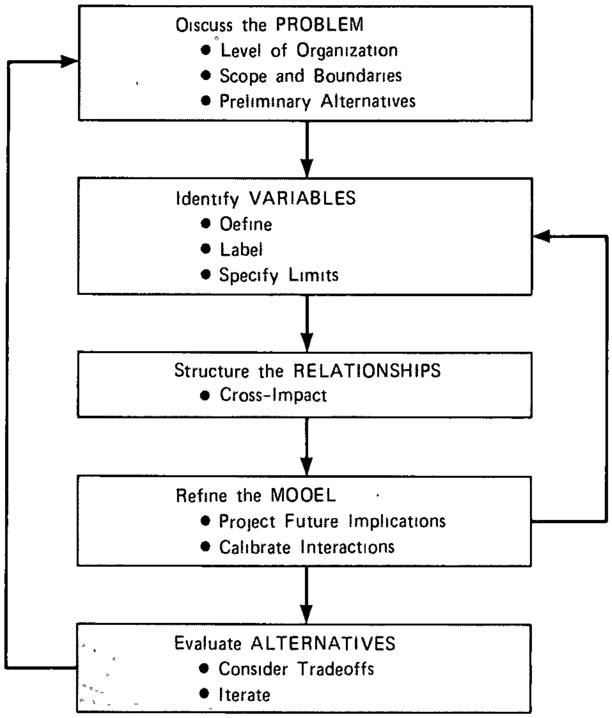
". . . almost no issues having long term implications can be resolved without recourse to intuition."

Russell R. Rhyne

Steps in the Procedure

The steps in the KSIM procedure are depicted below:

STEPS IN THE PROCEDURE



Discuss the Problem. The problem is initially discussed by the team members. This should be done in a conversational manner, encouraging a free wheeling, imaginative exchange of ideas relating to the problem.

After such a discussion, the problem is ready to be structured in terms of a system of interacting variables. First a consensus must be reached concerning the level of aggregation – is it to be global, national, regional, local? Next, a spatial boundary must be set, the three state region comprised of Washington, Oregon and Idaho, for example. A temporal boundary, such as the next 10 years, must then be agreed upon.

Consensus must also be reached on other basic assumptions, for example, that the population in the region will grow at an average annual rate of two percent. At the same time, lists of alternative assumptions should be made. Alternative population growth rates could be zero population growth, a rate higher than two percent, or net population loss over the next ten years

Identify Variables. The system's variables are then identified, defined, and labeled. It should be noted that a definition of a variable can differ according to certain levels of aggregation. At the global level, the performance definition of the variable "economic health" might be stated in terms of world trade. At the local level, however, "economic health" might be expressed as the average level of employment within the time period of the problem.

A variable can be defined to include more than one measure. The local "economic health" variable could express average per capita income, private and public capital investment, or any combination of employment, income and investment.

The measures chosen to define the variable should reflect what the team feels will be the primary concerns during the period in question. For example, though the "water resources" variable of a regional system may include recreation opportunities, water supply, waste disposal, flood plain management, and navigation, the team may decide that the most important of these for the future of the region will be supply and waste disposal. In this case, the variable "water resources" would be measured in terms of water supply and waste disposal capacity. To facilitate identification in the computer printout, each variable is assigned a label, usually in the form of an acronym, short title, or abbreviation.

Minimum and maximum limits must also be set for each variable. During this step, each variable is "normalized" by setting its maximum value at one and its minimum value at zero. Current values are then estimated within the zero to one range. For example, if the maximum population capacity of the U.S. is estimated at 500 million people, then 500 million is set equal to one and no people would represent the minimum or zero value Since today's population of 220 million people is 44 percent of the maximum, the current value is set at 0.44.

Structure the Relationships. A model is structured by completing a cross-impact matrix to identify the impact of one variable upon another. The variable labels are listed as row and column headings of a table. A basic assumption is that when one variable changes, a second variable may be completely unaffected, or may be encouraged or inhibited. To show this, during the initial phase of KSIM the variables are assigned cross-impact values of (0) for unrelated, (+) for encouraged, or (-) for inhibited. Completing the cross-impact matrix in this way provides the initial structure for the model. Refinements are made by assigning numerical values to these preliminary cross-impact estimates.

Refine the Model. This step is based on the concept that a variable increases or decreases according to whether the net impact of the other variables is positive or negative. Variables, initial values, and cross-impact values are typed into a computer. The computer then performs the iterative calculations and displays the projected changes in each variable over time. It is at this time that participants modify and refine their model by adding or deleting variables, redefining the limits of variables, or modifying the numerical impact relationships. This step is repeated until the participants are satisfied that the overall model and agreed upon variables represent their perception of the actual situation.

Evaluate Alternatives. Planning alternatives (or interventions) can now be tested. This is done by changing initial values, basic assumptions, or relationships, or by introducing exogenous impacts. When a team member suggests an intervention, the future consequences of the change can be displayed for consideration in a matter of minutes. Planners examine the outputs to identify tradeoffs among variables and can reexamine planning objectives. In addition to testing alternatives, the group can evaluate the implications of external changes such as shifts in public priorities or technological breakthroughs.

CROSS-IMPACT MATRIX

In 1968, Theodore J. Gordon reported on his research at University of California, Los Angeles, in cross-impact forecasting. Gordon used Olaf Helmer's term, "cross-impact," to describe the relationships between events. He arranged items in a matrix form and described the relationship between items in terms of LINKAGES. The LINKAGES in the cross-impact matrix were determined by:

(1) Direction: There are three modes, UNAFFECTED, ENHANCED, or INHIBITED.

(2) Strength: How strongly does the occurrence of one item influence the other?

(3) Time: "How long an interval is required before another item is influenced?"

Assume that a variable changes. A second variable may be completely unaffected, it may be encouraged, or it may be inhibited.

There are several ways in which a change in one variable can encourage another variable:

- The occurrence of one variable makes it necessary to try to bring about the occurrence of another variable. Gordon refers to this type of enhancing relationship as PROVOKING.
- A change in one variable indicates that a change in another variable is feasible or practical. This type of enhancing relationship is called ENABLING.

Inhibiting linkages, where one variable inhibits another, also result from several mechanisms, including:

- A change in one variable indicates that another event is unfeasible or impractical. This type of inhibiting relationship is referred to as DENIGRATING.
- The occurrence of one item requires that another item decline. This type of inhibiting relationship is called ANTAGONISTIC.

While Gordon used the cross-impact matrix to deal with cumulative probabilities of events occurring, the KSIM technique deals with the actual occurrence of change in variables in a deterministic manner.

EXAMPLES OF LINKAGES

Examples	Enhancing		Inhibiting	
	Enabling	Provoking	Denigrating	Antagonistic
Historical	A political party nomination is a prerequisite for the presidency	Population increases made development of birth control devices more important	1830 railroad development delayed automobile	Vietnam conflict is antagonistic to reduction of income tax
Future	Advent of a very cheap power service will promote desalination	Large increase in atmospheric contamination will prompt the development of non-contaminating power sources	Discovery of pathogenic organisms on Mars will make manned planetary exploration more difficult	Increasing crime rate may result in anarchy

Source. Theodore J. Gordon, "Initial Experiments with Cross-Impact Matrix Method of Forecasting," 1968.

PROBLEM

A county official is asked to open a wilderness area, Eco Valley, for hunting. A local sports club maintains there is an overpopulation of hawks and Eco Valley is perfect for a recreational area. The city conservation society has kept records of the Valley for years and would like to present their data.

The city official, together with the sportsmen, conservationist, resident ecologist and city planner meet to discuss "the Eco Valley situation." They address the question: "Shall we permit bird hunting in Eco Valley?" The team discusses the physical boundaries, the biological habitat, and the time frame over which they wish to consider the problem:

Physical boundaries – 10 sq. miles of land
Biological habitat – Hawks, Rabbits, Grass
Time frame – 30 years

VARIABLES

The variables are identified as Hawks, Rabbits, and Grassland. These variables are labeled and discussed in terms of growth limits, where the minimum value is set equal to zero and the maximum value set equal to one. For example, no hawks would represent the minimum, equal to zero, and 500 hawks per square mile would represent a maximum value of one. Data indicate that there are presently 250 hawks per square mile; thus, the initial value for hawks is 0.5 or 50 percent of the maximum possible number of hawks. In the case of grass, there was some consideration given to the idea that zero grass might not be the lower limit. Actually, the minimum would represent some state where grass would no longer grow, such as complete soil depletion or a paved-over area. However, the group decided first to try the model as specified below and then later redefine the limits of this variable and rerun the model to test the sensitivity of this variable.

Variable	Label	Limits		Present	Initial Value
		Min.	Max.		
Hawks	H	0	500/sq. mi.	250/sq. mi.	50%
Rabbits	R	0	2500/sq. mi	1000/sq. mi.	40%
Grassland	G	0	10/sq. mi.	8/sq. mi.	80%

IMPACTS

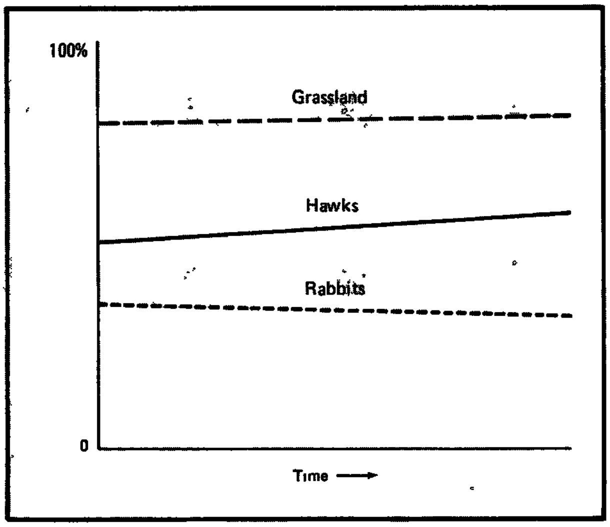
The variables are written as the row and column titles of a matrix, as indicated below. The initial values are shown in parentheses beside the variable table. A fourth column is added to allow for interventions from the outside world. For each square, the team determines the impact of the column variable (A) upon the row variable (B). The matrix is filled in by answering the following questions: Is A related to B? If so, will a change in A encourage (+) or inhibit (-) B? The interaction will depend both on the relative size of the variable and the magnitude of the impact. Cross impact values are generally considered as strong, medium or mild and range in value between plus and minus three. Zero indicates no interaction. The impact of A upon B is written A:B and then the motivation for each choice is described.

B	A			
	H (.5)	R (.4)	G (.8)	OW
Hawks	+1	+1	-1	
Rabbits	-2	+3	0	
Grassland	0	-2	+1	

Hawks: Hawks (+1)	The breeding cycle indicated a slight increase.
Rabbits: Hawks (+1)	Rabbits provide food for hawks.
Grassland: Hawks (-1)	After much discussion and considering the high density of grasslands, the group concluded any increase in grasslands would hide the rabbits from the hawks and the hawk population would decline. The impact is very slight.
Hawks: Rabbits (-2)	Hawks are the main predator and feed primarily on the rabbits.
Rabbits: Rabbits (+3)	Rabbits were judged to breed about three times as fast as hawks.
Rabbits: Grassland (+2)	The more rabbits there are, the less grassland.
Grassland: Rabbits (0)	Depending upon the state of the system, there might be some interaction. However, unless variables are close to maximum or minimum, there is no significant impact.
Grassland: Grassland (+1)	There is a regenerative effect, again up to a point.

REFINEMENT

The data from the cross-impact matrix is typed into the computer and changes in all three variables over the next 30 years are displayed. After reviewing the projections, the group decides to make two modifications. First they decide to describe the relationship between rabbits and grassland in more detail. The ecologist and conservationist present the details of seasonal breeding versus changes in grassland due to weather, and then include this refinement into the model. They also feel that they have overlooked an important negative impact on hawks from outside the valley that should be included. Observing what they consider to be a realistic stable behavior for Eco Valley, the group can use this model to test alternative actions:



ALTERNATIVES

The question to be answered is, "Shall we allow hawk hunting?" A negative impact on hawks results in a decrease in hawks, an increase in rabbits, and at the peak of the rabbit population, a decline in grasslands.

Further consideration indicates that if hawk hunting is allowed, the entrance of people into the valley will probably destroy some grass. Adding even a moderate negative impact on grass results in a dangerous decline in all variables. The rapid growth in the rabbit population due to the decline in hawks causes the grasslands to be diminished even more rapidly. But then, as the grasslands draw below 30 percent cover, the rabbit population is endangered. There seems to be a balance between the hawks, rabbits and grass that must be maintained.

More questions arise.

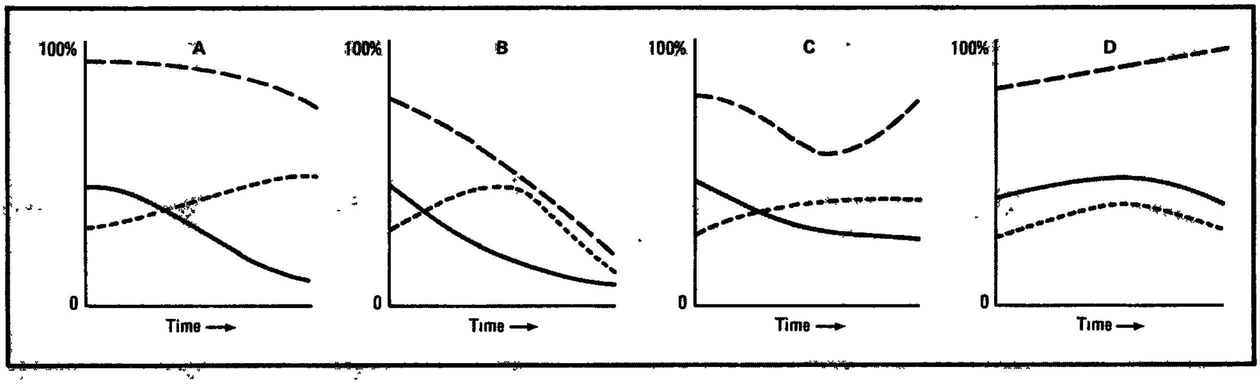
A. If hawk hunting is allowed, shall we allow vehicles? What about roads?

B. With grassland maintenance, maybe seasonal hunting would be OK?

C. Will the hunters shoot rabbits? Do we want a "hawks only" policy? How do we enforce such a policy?

D. Should the system be expanded to consider the influx of new hawks from outlying regions? What about man?

For each question, the committee structures impacts, reviews the results, and compares the alternatives. By the end of the meeting, they have a refined set of alternatives along with their probable outcomes. Moreover, the problem is well structured and generally supported by a strong consensus from having worked together to bring to the surface the real issues and concerns.



APPLICATION OF KSIM TO WATER RESOURCE PLANNING – AN EXAMPLE

An urban water planning situation will be used in this report to illustrate the application of KSIM to water resource planning. The focus of the example will be to assess the effects of water resources development upon such urban considerations as provision of services, employment patterns, and changes in residential preferences.

The KSIM team consisted of eight members, who contributed the following disciplines, affiliations and points of view:

Urban Study Manager	District Planner
Resource Geographer	Division Planner
Urban Planner	District Planner
Urban Economist	District Planner
Civil Engineer	Local Planning Representative
Regional Economist	Local Planning Representative
Water Resource Planner	Research Manager
Systems Analyst	KSIM Coordinator

The Corps members from one district included the Chief of the Project Formulation Section, as well as an urban planner and an economist familiar with the study problem. The resource geographer was born and raised in the study area, and both he and one of the other planners (a 20-year resident) gave two views of local preferences. The local planning representatives had experience in water resource management, employment, and regional government. Concentrating on water-related and urban conditions, the KSIM team began by discussing the major components of the study area.

Problem Formulation

Designing a model of the urban area in the broadest terms, the team identified two major components: water and land resources, and the people who use them. In a discussion of needs, the economic factors controlling the development of area resources and the provision of urban services (transportation, water, and other utilities) were defined. Urban services were seen as directly affecting population density, jobs, and lifestyles.

Figure 1 – PROBLEM FORMULATION

The nature of the problem is dependent upon individual perception and frame of reference

After considerable discussion and debate (on the order of four hours), the team began to arrange some forty problem and affected areas into an aggregated systems framework.

On the local level, there were a number of important considerations. Residential preferences and implications of development for changing lifestyles came into sharp focus as special local concerns, and institutional arrangements such as the existence of a number of different local water agencies emerged as major constraints in implementing effective planning alternatives. However, since the major water resource considerations were primarily regional in nature, the level of organization for the model was selected to be regional. Local considerations can be brought into the system later. Higher level activities outside the regional area, however, do exert external influences, and these should be considered. Such "outside world" variables include national policy statements in land, housing, and growth. Federal environmental legislation, national resource constraints in terms of energy availability, and aspects of foreign trade and aggregate U.S. national production of goods and services were also cited as influential outside factors. Such external constraints are termed exogenous variables – ones that are outside the system. Unlike system variables, these variables may act upon the system but they are not significantly affected by the system. Collectively referred to as "an outside world variable," they are usually included to complete a balanced model, as well as to assess the effects of external changes upon the system variables.

Having established a regional framework, the next concern of the team was to define the boundaries of the system. The regional area was defined in terms of political jurisdiction, land, and physical characteristics. The specific geographical boundaries were defined to encompass an eight-county metropolitan area. Detailed planning assumptions about population and employment were introduced to help clarify the boundary conditions, and these are delineated in Table 2. The time frame selected for the model was a period of fifty years, during which significant variable interactions that would affect planning could be observed.

To focus on the regional development problems, the team agreed to follow current development trends and policies in the region. For purposes of developing a base model, they assumed no extensive rapid transit system development in the next 20 or 30 years. In the absence of rapid transit, the factors assumed to be most influential in the location of new development were the existing and committed transportation, sewer, and water systems.

Variable Identification

The team designed its model in terms of seven interacting variables labelled as follows: Urban services (US), employment dispersal (ED), flexibility of choice (FOC), residential density (RD), water demand (H_2O), satisfaction (SAT), and costs ($). An exogenous variable labelled outside world (OW) was also included.

Table 2
PLANNING ASSUMPTIONS CONCERNING POPULATION AND EMPLOYMENT

The following assumptions were made to guide the population distribution:

- Metro centers (focal points for commercial and industrial development, residential concentrations, public services and other community facilities) will develop at the intersections of radial and circumferential highway routes and will influence residential development.
- Existing and planned utilities (such as water lines and sewer lines) and transportation facilities (such as freeways and expressways) will influence residential location, especially since the capital costs of such new construction are so high.
- All land designated as planned open space, flood plains, or as having steep slopes, is undesirable for residential development and should not be built upon unless development has already occurred there.
- Loss of population in the central city areas will continue at a reduced rate after 1980 because public and private actions will begin to offset existing trends in the central city.
- All known planned or initiated developments were incorporated in the distribution even if not in conformance with the metro center or planned utilities concepts.

The following assumptions were made to guide the employment distribution:

- Between 1974 and 1984, most existing employment will remain where it is now. After 1980, employment relocations are anticipated.
- Throughout the period 1974 to 2000, substantial employment growth will take place in metro centers.
- All initiated and planned new development is incorporated into the employment distribution.
- Much of the projected industrial employment will be located in existing or planned industrial areas. However, a decline in industrial employment is anticipated in and near the central business district after 1980.
- Most projected retail and service employment will be primarily located in existing employment areas and metro centers. Retail employment in the central business district will continue to decrease, but at a slower rate.
- Retail employment in the central city area (other than the central business districts) will decrease in proportion to the projected population decrease.
- Projected government employment will be expanded where it presently exists and also will locate in areas of rapid population increase.
- Other employment (meaning not industrial related goods and services) will be located in areas of high employment concentrations and in areas of rapid population growth.

All variables were defined in terms of perceived growth or decline levels, the limits being a minimum threshold and full saturation. Describing residential density, an obvious minimum threshold would be the absence of people. To define some finite upper density would depend upon one's judgment as to maximum allowable number of people per acre. The maximum may be either measured or judged. The number itself need not be exact since it can be normalized to a scale with a lower limit of zero and an upper limit of one. With this type of definition, all variables become dimensionless and can be expressed as percentages. This also takes full advantage of the psychological perception process. Often planners do not know the dimensions of social problems and yet must articulate estimates. Subjective variables are much easier to express as fractions of an ideal rather than as an absolute number. For many such variables an absolute value conveys no meaning at all, a ratio to some standard is more representative. The percentage figure assigned to each variable was the KSIM team's estimate of the level of conditions prevailing in 1973. This initial value furnished a base for calculating changes over time. The following definitions indicate the limits and current values of variables used in this example.

Urban Services (US) indicates the degree of urbanization of the region. It is the fraction of total area provided with services and facilities other than water resources. While this variable is particularly sensitive to public transportation services, it also includes such items as streets, police, schools, fire protection, hospitals, public utilities, libraries, and cultural and recreational facilities. There are 3,480 square miles in the region. Assuming 940 square miles have urban service coverage, the current urban service coverage is assessed at 27 percent.

Employment Dispersal (ED) indicates the overall travel time in the region. It refers to the distribution of employment centers throughout the region and is a function of the number of work centers and their distance apart. Because the team did not have sufficient data to calculate ED accurately, the current value was estimated at 40 percent. Pending further documentation ED can be measured in terms of weekly hours spent commuting and total work hours.

Flexibility of Choice (FOC) is an indicator of the range of socioeconomic opportunities and the overall attractiveness of the region. It is an estimate of the variety of choices of life styles that are available in the region, considering educational level, recreation opportunity, job skills, base income, mobility and cultural heterogeneity. The subjective estimate of flexibility is 50 percent. This implies that the team felt the maximum possible choices that people of the region could have is twice that at present.

Residential Density (RD) is an indicator of urban sprawl and is calçulated by dividing the number of people in the region by the total acres of land in residential use. It was decided to set maximum possible density at 30 people per residential acre as an assumed regional planning limit. Currently, there are nine people per residential acre, or an RD of 30 percent.

Water Demand (H_2O) reflects the degree to which the physical water resource base and management capabilities are utilized. It indicates the demands on the institutional structure in managing water resources. Currently about 60 percent of the possible water demand is being serviced.

Satisfaction (SAT) is an indicator of the overall regional confidence, measured in terms of people's desire to live in the area. The variable was introduced to reflect different perceptions based on a variety of cultural preferences. The subjective level of satisfaction is perceived to be 70 percent. This implies that people feel they are more than half way to "bliss" but still feel possibility for improvement.

Costs ($) indicate the rise or possible decline in taxes. It provides the balance between demand for government services and desire to pay. It is defined in terms of the cost of providing regional services as a fraction of gross regional product (GRP) and measures the overall cost of providing public services. The costs are presently about 20 percent of GRP, indicating that one dollar out of five is being spent for public services.

Summarized below are the limits and current values of the regional variables.

- Urban Services (US) — 27 percent
  1 = area completely serviced
  0 = no services
  0.27 = initial value
- Employment Dispersal (ED) — 40 percent
  1 = equal dispersion
  0 = single location
  0.4 = initial value
- Flexibility of Choice (FOC) — 50 percent
  1 = every possible option
  0 = no choice
  0.5 = initial value
- Residential Density (RD) — 30 percent
  1 = 30 people/acre
  0 = no people
  0.3 = initial value
- Water Demand (H_2O) — 60 percent
  1 = perfect service
  0 = no service
  0.6 = initial value
- Satisfaction (SAT) — 70 percent
  1 = no one leaves
  0 = everyone would like to leave
  0.7 = initial value
- Costs ($) — 20 percent
  1 = all GRP to services
  0 = no GRP to services
  0.2 = initial value

Cross-Impact

Once the variables are defined, establishing the relationship between each pair of variables structures the base model. This is done by completing a cross-impact matrix. Variables are listed as the column and row heading of a matrix, and relationships are assigned by establishing an impact assumption about the effect of a column variable on each row variable. With this procedure, no binary interactions can be overlooked. All relationships must be considered. Experience indicates that a good procedure for establishing the connections between variables is first to establish whether or not there is a relationship, and then to identify the type and strength of the relationship. For example, the following question is asked: Is there a relationship between urban services and residential density? If so, is the relationship positive, encouraging growth, or negative, tending to inhibit growth? Is the relationship mild, significant, or strong?

Filling out the cross-impact matrices fosters disciplined, organized discussion. In a non-authoritarian structure each team member has equal say and must be ready to defend his position. Each member evaluates each impact relationship and thereby "votes." Discussion then follows to allow insights of each to be expressed and the "votes" to be reevaluated. Usually in this process variables will be clarified or redefined. This is very important. In defining a system, it is necessary to keep open constant possible redefinition of the variables. Thus, the meaning of a variable might be continually changing, as in the case of a variable labelled "employment land use." This variable referred originally to the distribution of employment centers throughout the region, describing the number of work centers and their spatial arrangement. Eventually the team came to grips with the concept of Employment Dispersal as indicating overall travel time in the region.

To structure the regional model, two impact matrices were completed. The first matrix represents the constant or long-term relationships between variables, while the other accounts for effects of changes in one variable upon the other variable. Loosely speaking, the second matrix can be thought of as describing short-term relationships. Tables 3 and 4 show the respective long-term and short-term matrices completed by the team for the regional model. The matrix values (referred to as alpha and beta) range between zero and plus or minus three indicating strength of relationship. Thus, zero indicates no influence, and plus or minus three would signify a strong positive or negative influence. The range is arbitrary and could have as easily been set between zero and plus or minus ten. The actual scaling of the matrix values is described in the box, "Understanding Alpha and Beta." *The idea is to judge the relative impact.* That is, using actual data or judgment, to estimate the relative degree of change that one variable causes in another variable. If more services and higher density each increases the demand for water, is one a more powerful influence than the other? The relative influence is specified by the strength of the number assigned. While the alpha

Table 3 – LONG-TERM IMPACT MATRIX*

B	A							
	US(.27)	ED(.4)	FOC(.5)	RD(.3)	H_2O(.6)	SAT(.7)	$(.2)	OW(1)
Urban Services (US)	1.25	.75	1.4	–1.9	0	–1	1.6	
Employment Dispersal (ED)	1.63	2.5	.87	–1.6	–.12	0	0	
Flexibility of Choice (FOC)	1.5	1.4	1.25	– .25	0	0	1	
Residential Density (RD)	–2	–1	–.5	.5	.75	0	0	
Water Demand (H_2O)	2	2	1.87	–1.4	–.5	0	0	
Satisfaction (SAT)	.75	A	1	– .25	–1.12	B	–1.3	
Costs ($)	1	1.5	1	– .75	1.6	–1	1	

*Entries represent the impact of the column variable A on the row variable B. Zero indicates no impact. Letters indicate functional entries. The initial values are shown in parenthesis.

Table 4 – SHORT-TERM IMPACT MATRIX*

B	A							
	US(.27)	ED(.4)	F.OC(.5)	RD(.3)	H_2O(.6)	SAT(.7)	$(.2)	OW(1)
Urban Services (US)	25	–.75	.25	–.7	– .12	0	1	
Employment Dispersal (ED)	.13	.6	0	0	0	0	0	
Flexibility of Choice (FOC)	.75	25	.25	–.25	0	0	0	
Residential Density (RD)	0	.25	0	0	0	0	0	
Water Demand (H_2O)	.5	5	.25	0	0	0	0	
Satisfaction (SAT)	13	–1	1 75	– 75	–1.5	1 9	–2	
Costs ($)	1.4	.5	.25	– 38	.25	0	–.3	

*Entries represent the impact of the column variable A on the row variable B Zero indicates no impact. Letters indicate functional entries. The initial values are shown in parenthesis

or constant relationships are usually the more powerful factors influencing the behavior of the model, the beta or short-term relationships play an important role when a period of rapid change is anticipated.

Refine the Model

During this step, team members used a remote terminal and the KSIM computer program to project and calibrate the behavior of the regional model The program is conversational and can be operated by any of the team members. Team members entered initial values and the values from the two impact matrices into the computer via the remote terminal and could thereby generate their own output. The basic output from the terminal is a plotted forecast of all variables as they change over the projected time period. In the time-shared mode, a typical run can be completed in two minutes. Utilizing this quick feedback, participants updated the model by.

- Adding or deleting variables;
- Changing impact relationships; or
- Changing an initial value of one or more variables.

The team was able to conduct sensitivity analyses on the model to determine where refinement was needed. For example, the initial value of the employment dispersal variable was changed from 60 percent to 40 percent, and a need for further documentation was noted. In analyz-

UNDERSTANDING ALPHA AND BETA

In order to understand the role of alpha (α) and beta (β), consider the following example: A car travels along the road from Point A to Point B and uses fuel. The car has a speedometer but no gas gauge. What happens to the gasoline flow (rate of emptying the tank) for different driving policies?

The fuel consumed varies with constant speed and changes in speed.

α REPRESENTS THE *LONG-TERM* RELATIONSHIP BETWEEN *SPEED* AND FUEL

β REPRESENTS THE *SHORT-TERM* RELATIONSHIP BETWEEN *CHANGE IN SPEED* AND FUEL

At any given constant speed, α is calculated by dividing fuel consumption by the speed. Thus, for a car traveling 55 mph, using 2 gallons of fuel in that hour, α equals 2 ÷ 55 or 0.036 gallons/mile.

Once α is specified, the fuel consumed at other speeds can be determined by multiplying α times the speed. For example, driving at 40 mph for 1 hour, the fuel consumed is 40 x 0.036 or 1.45 gallons/hour.

Unfortunately, constant speed over time is unlikely, and thus using α will not be a sufficient measure. How much more or less gasoline will be used when changing speed? β is introduced to account for the short-term changes in speed, such as passing or slowing in traffic. β works with *change in speed* just like α works with *constant speed*.

For a given change in speed, β is calculated by dividing the fuel consumption by the change in speed.

Thus, if acceleration from 55 mph to 65 mph in 3 minutes (a change in speed of 3.3 mph per minute) requires an additional 0.1 gallon of gas (2 gallons per hour in one hour), β equals 2 ÷ 3.3 = 0.6 gallons per hour/mph per minute.

Again, once β is specified, the fuel consumed for other changes in speed can be determined by multiplying the change in speed times β. Accelerating from 40 mph to 50 mph in 2 minutes, (a change in speed of 5 mph per minute) the gas consumption is 5 x 0.6 or 3.0 gallons per hour.

Adding the 3.0 gallons to the 1.45 gallons consumed at 40 mph results in a fuel consumption of 4.45 gallons per hour.

In the cross-impact matrix, the mild long-term impact of speed on fuel is indicated by α = 1. A strong short-term impact is shown as β = 3. These cross-impact values must be SCALED to reflect the real situation.

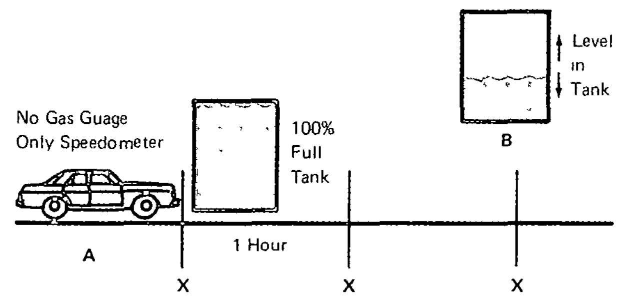
The scaling factors are simply calculated by dividing the real value by the cross-impact value. In this example, since the real value of α is 0.036, the scaling factor is

$$0.036 \div 1 = 0.036$$

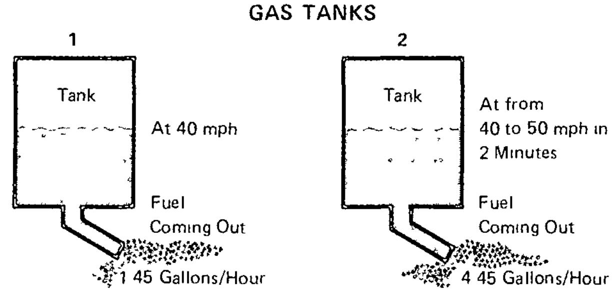
For β, the scaling factor is

$$0.6 \div 3 = 0.2$$

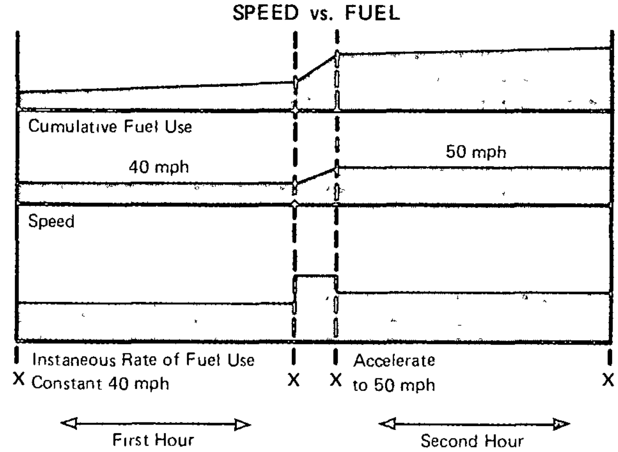
AUTO



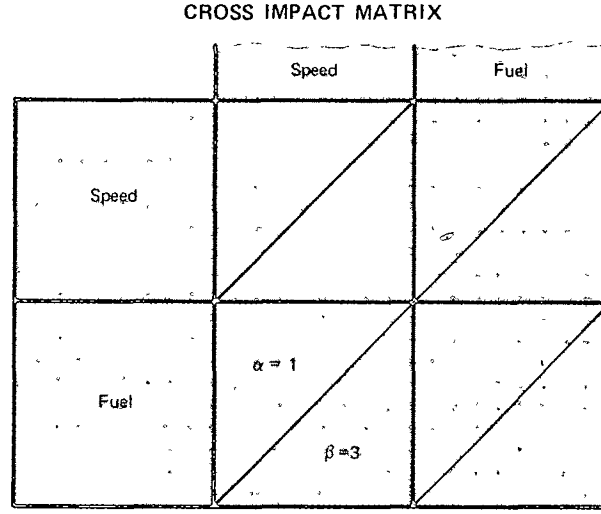
GAS TANKS



SPEED vs. FUEL



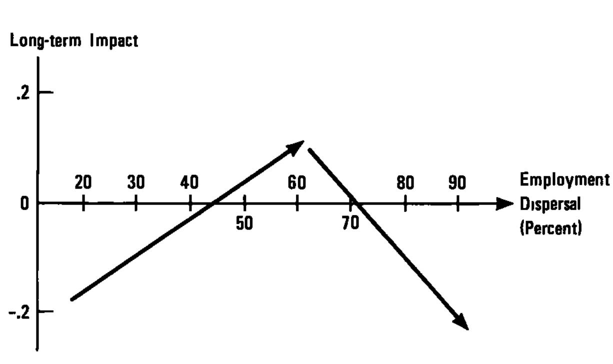
CROSS IMPACT MATRIX



ing the output, participants can reassess any or all input estimates.

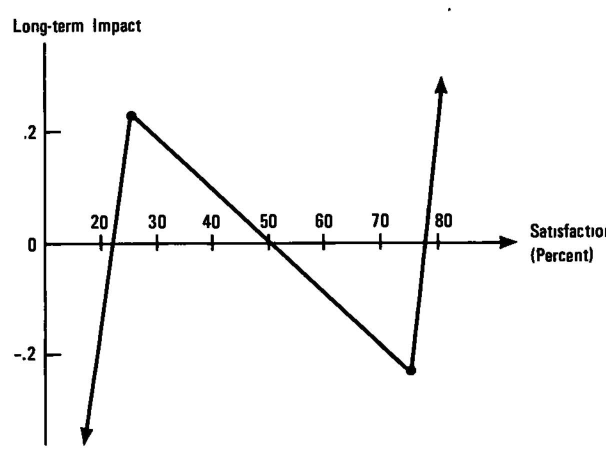
The reassessment of cross-impacts provides an opportunity for considerable refinement, as certain impacts can be more precisely expressed as functional relationships rather than as constants. Instead of maintaining a constant impact (positive, negative or zero), some variables tend to stimulate growth up to a certain point and then lose their influence, or they may switch to negative impact and possibly inhibit growth. Also, significant interactions may have been overlooked. Working with seven variables and an outside world column means that there are some 112 interactions to be discussed. During the refinement stage, the panel focused on some of the more complex variable relationships. For example, they changed two of the impacts from constants to functional relationships. The impact of employment dispersal on satisfaction was revised to be a functional relationship with reasoning as follows: when there is a single employment center, the impact of greater or fewer jobs on satisfaction is slight. As employment centers become more dispersed, with a drop in overall travel time, the impact on satisfaction is more positive. It is assumed that this positive influence begins to decline around 60 percent employment dispersal, and finally people experience dissatisfaction as the job centers become almost totally dispersed. This is illustrated in Figure 2.

Figure 2 – LONG-TERM IMPACT OF EMPLOYMENT DISPERSAL ON SATISFACTION



The impact of satisfaction upon satisfaction is a different case. Research studies indicate that satisfaction has a self-stabilizing effect. Satisfaction seems to encourage satisfaction only for a short time, and satisfaction declines when factors that attracted people to the region begin to be taken for granted. Similarly, when conditions are discouraging, hope for improvement can reverse the trend of dissatisfaction. However, it was assumed that should satisfaction ever go below 25 percent or above 75 percent, the self-stabilizing concept would be overstrained. The team felt that the citizen would either be so confident that he would not leave the region or else so depressed that nothing would keep him there. This functional relationship is depicted by the N-shaped diagram below.

Figure 3 – LONG-TERM IMPACT OF SATISFACTION ON SATISFACTION

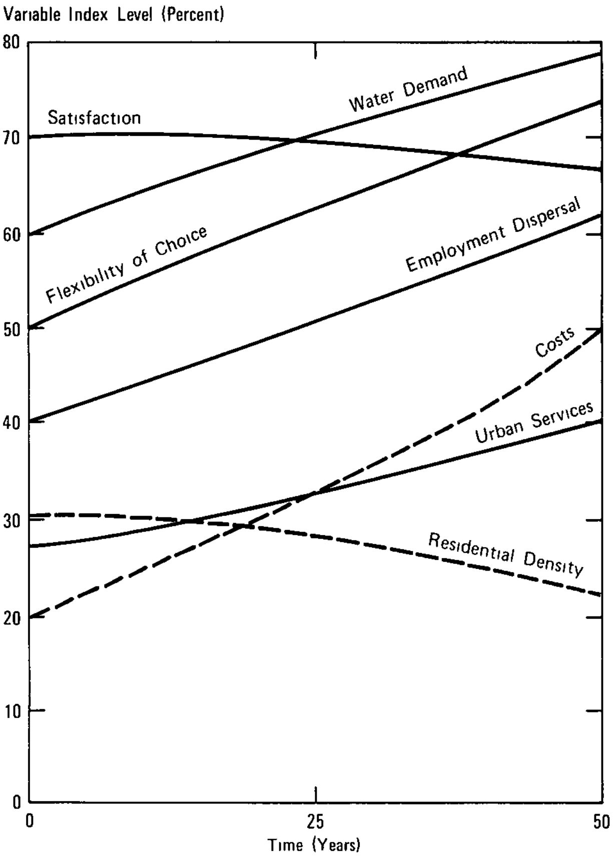


Test and Evaluate Alternatives

The Regional Model

Having defined the variables and agreed upon and refined some growth characteristics and impact relationships, the team used the on-line computer program to project future conditions of the regional system. The behavior of the system that emerged from the set of assumptions believed to reflect the current regional trends is illustrated below.

Figure 4 – THE REGIONAL MODEL



The area experiences a continuing trend toward urbanization, shown by the increase in the *urban services* variable. This follows from an assumption that without a rapid transit system growth will concentrate near the junctions of existing and planned highways. This will mean the development at junctions of metrocenters which will serve as focal points for local business growth. Decrease in time spent commuting, due to more widely dispersed employment locations, was also reasoned as a factor to diminish support for a rapid transit system, as well as to increase the trend toward dispersal. This effect is shown by rapid growth pattern in the *employment dispersal* variable. With a more dispersed urban region, it is assumed that more *flexibility of choices* will become available.

These increases in urban services, employment dispersal, and greater variety of life styles all tend to create increased *water demand,* in terms of water supply, waste water treatment and disposal, flood protection, and water-related recreation. This means that more stress will be placed on planners and decision makers to develop, allocate, and manage regional water resources, and this will result in increased *costs.* It can be expected that this will result in more pressure placed on the regional institutions to adopt a unified approach to meet the growing water requirements of urbanization with greater efficiency.

While socioeconomic opportunities increase in this case run, the overall *satisfaction* in the region declines. This decline is due mainly to the assumption of a strong negative impact of a rise in costs on satisfaction. Even though a wider range of choice is developing (in such areas as educational level, recreation opportunity, job skills, and cultural preference), the satisfaction they engender is deterred by a sharp rise in taxes. This reflects the model assumption that the costs of public services will balance out the demand for them, and the desire to pay, as well. The satisfaction variable is also introduced to reflect differing cultural perceptions of what constitutes satisfaction.

The *residential density* variable is an indicator of urban sprawl, and its increase indicates a population shift to the suburban areas. This is consistent with actual trends which show losses of more than 100,000 persons from the central cities of the region from 1930 to 1970.

These general patterns satisfied the team as fulfilling the basic planning assumptions and cross-impact relationships. It also simulated further discussion of planning trade-offs. Some team members felt that regardless of the greater cost and flexibility options that accompany urbanization, many residents would resent *any* plan bringing further development to the region.

Planning Trade-offs

Once satisfied with the general characteristics of the model, the team began to explore a number of planning alternatives. This is done in either of two ways:

- Altering the state of the system by intervening from outside, or
- Altering the structure of the system by changing connections between variables.

There is an important distinction between altering the state of the system and altering the structure of the system. An intervention that alters the state of the system can have a temporary effect. Once the policy introducing change expires, the system will usually return to its former equilibrium. On the other hand, a change in the structure of the system will result in an entirely new equilibrium position. For example, in order to accommodate the team suggestion regarding the negative impact of any development plan an overall satisfaction, a new set of impact relationships would emerge.

Testing and evaluation of the model can be done as a group or individually. This team did both. Over forty different cases were simulated, and three of the planning options discussed by the group have been selected and are illustrated in this section:

Case I - increased residential density from rapid transit

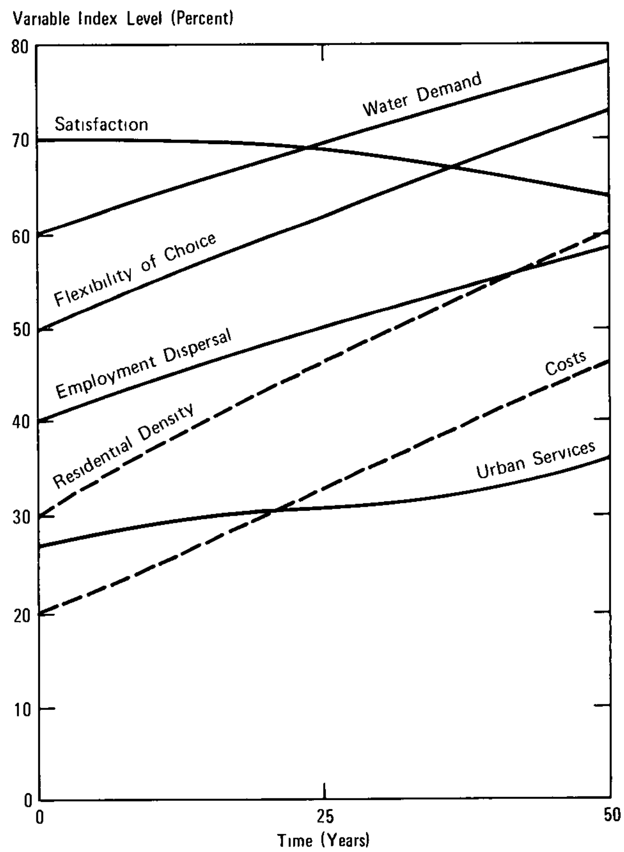
Case II - limited residential density accompanied by a greater flexibility of choice

Case III - long-term energy shortage.

For Case I, the team assumed that a rapid mass transit system would be constructed to serve the region Anticipating that a rapid transit system would foster a more centralized regional growth pattern, Case I was simulated by giving a strong positive impact to increased residential density. The resulting effects on the model (Figure 5) show that increased residential density reverses the trend in the regional model. Growth of urban services is slower, and employment dispersal is only slightly less than that of the regional model. Satisfaction within the region, flexibility of choice, and water demand remain essentially unchanged. A small reduction in costs is projected.

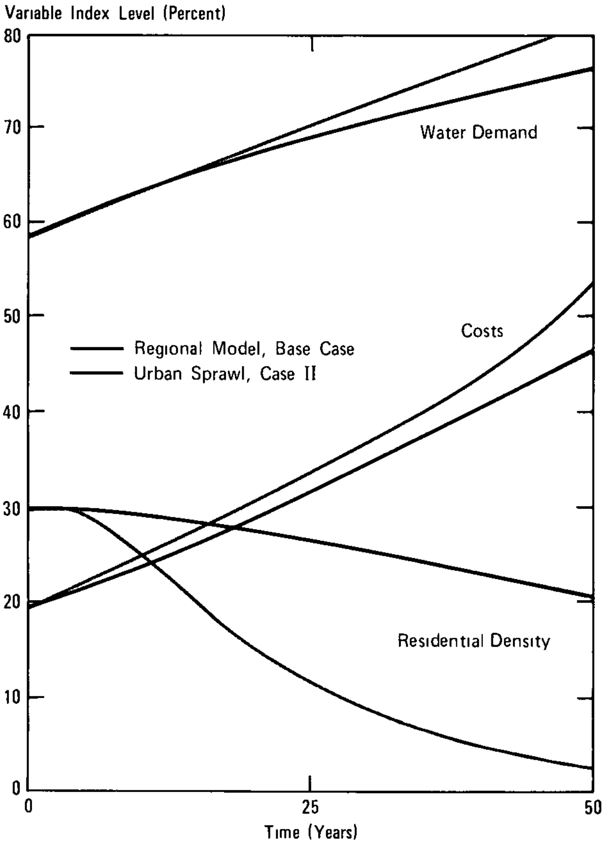
The overall interpretation of this case suggests an alternative future that is very concentrated and urban with many separate employment centers. Thus, a high usage for the transit system is likely, and it appears that the water resource requirements, in the aggregate, will be about the same as the base case. Because of the concentrated urban population, some economies are suggested at the lower cost level. Probably the major difference in this case would be an emphasis on recreational use of water near the urban center.

Figure 5 – CASE I INCREASED RESIDENTIAL DENSITY FROM MASS TRANSIT



In Case II changes resulting from extended urban sprawl were simulated by limiting residential density. The team assumed that urban sprawl would continue at three times the recent rates for the next 50 years. The major differences between Case II and the base case are shown in Figure 6.

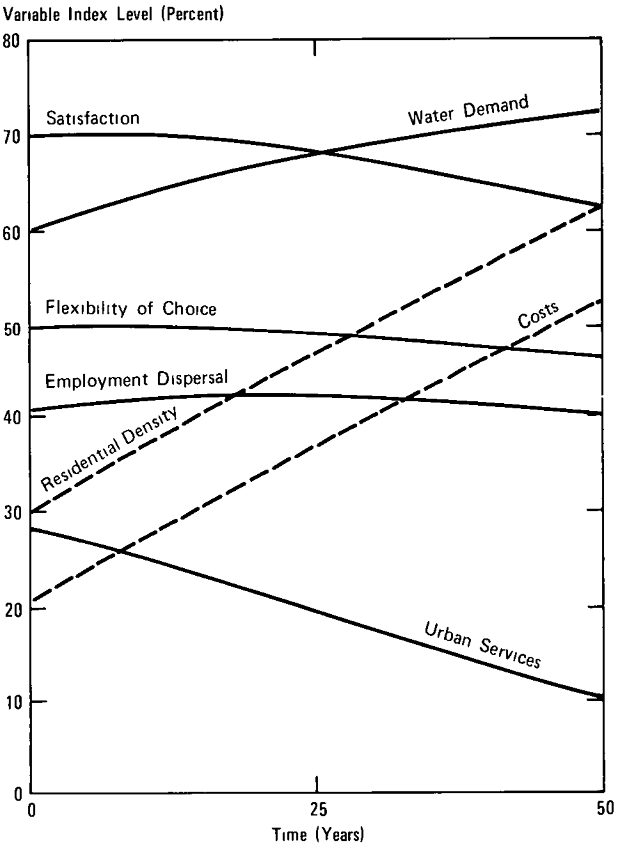
Figure 6 – CHANGES RESULTING FROM EXTENDED URBAN SPRAWL



The greatest demands on the total water resource picture resulted from rapid and almost total urban sprawl. Employment centers have spread throughout the region, and, as anticipated with greater urbanization, the demands for streets, police, schools, fire protection, hospitals, public utilities, libraries, and cultural and recreational facilities have driven up costs. Realizing that high costs would reduce satisfaction and regional confidence, the team reasoned that local policies would be required to maintain flexibility of choice. To offer a range of choice, however, would necessitate deliberate planning to increase the amenities and socioeconomic opportunities and overall attractiveness of the region. A complex task embracing the need for increased educational and recreational opportunities, job skills, base income, mobility, and cultural heterogeneity, it would require the participation of many other affected groups, in addition to water resources agencies and regional government.

Case II suggests a radically different alternative future from that of Case I. Here, the region is almost totally suburban with a large population distributed uniformly through the entire region. Water demand is increased to service more extensive areas, and consequently costs are proportionately higher. Water demand is at a

Figure 7 – CASE III: LONG-TERM ENERGY SHORTAGE



nearly maximum feasible level, and the major problems will very likely involve coping with shortages and meeting stringent allocation requirements demanded by other local agencies providing amenities to the dispersed populations.

For Case III, a long-term energy shortage was hypothesized. This would be reflected by negative impacts on urban services, opportunities, choice of life styles, and population dispersal. Figure 7 reflects these interventions and illustrates a subsequent drop in water resource demands, along with higher prices and a comparable measure of dissatisfaction. In this case the alternative future is one of continuing shortage.

Table 5 – EFFECTS OF PLANNING INTERVENTIONS ON THE GROWTH OF SYSTEM VARIABLES

	Year 0	Year 25	Year 50
Urban Services			
Case B- -Base Case	100	118	156
Case I- -Increase density	100	111	129
Case II- -Decreased density	100	130	178
Case III- -Energy shortage	100	52	30
Employment Dispersal			
Case B- -Base case	100	128	160
Case I- -Increase density	100	125	148
Case II- -Decreased density	100	133	168
Case III- -Energy shortage	100	102	95
Water Demand			
Case B- -Base case	100	117	133
Case I- -Increase density	100	115	128
Case II- -Decreased density	100	120	137
Case III- -Energy shortage	100	112	118
Flexibility of Choice			
Case B- -Base case	100	126	150
Case I- -Increase density	100	124	146
Case II- -Decreased density	100	148	176
Case III- -Energy shortage	100	96	90
Residential Density			
Case B- -Base case	100	83	63
Case I- -Increase density	100	157	200
Case II- -Decreased density	100	27	3
Case III- -Energy shortage	100	160	217
Satisfaction			
Case B- -Base case	100	97	91
Case I- -Increase density	100	96	90
Case II- -Decreased density	100	89	94
Case III- -Energy shortage	100	94	48
Costs			
Case B- -Base case	100	170	255
Case I- -Increase density	100	165	235
Case II- -Decreased density	100	175	275
Case III- -Energy shortage	100	190	270

As this situation evolves, it causes a continuous population movement back toward the central city with a very concentrated but small urban population. This means that a large fraction of the population will have left the region and suggests that water is again readily available. Perhaps the major problem facing water resources managers in this situation is obtaining sufficient budgets to maintain even minimum service and standards in the face of an extremely trying economic situation.

Table 5 summarizes the effects of the interventions on the growth of system variables. All values have been normalized with the first year set to 100. This summary table indicates that the biggest factor influencing water demand is the location of people but reflects also several other requirements that may be more important than merely meeting water demand. The trend toward urbanization increases resource demands, while concentration in developed areas stresses the ingenuity of planners and the flexibility of water resource institutions.

SUMMARY AND OUTLOOK

The preceding pages have described a computerized simulation procedure as well as one example of its application to a water resource planning problem. The increased complexity of planning and the need to consider the long term consequences of proposed projects make the KSIM simulation technique a particularly useful tool. As discussed earlier, KSIM can be especially helpful in first stage planning, in identifying needs, and in articulating planning objectives. KSIM is also valuable as a future oriented, quantitative technique to display the implications of individual attitudes, orientations, and perceptions of an issue or project at hand.

The value of any planning technique depends, however, not only on its ability to help solve planning problems but also on the skill with which it is applied. Though KSIM's methodological procedure is straight forward, its proper use requires much more than a simple step-by-step application.

Experience has shown that first time use is more productive if planners will familiarize themselves with KSIM's strengths, weaknesses and problems commonly encountered. (A summary of these is presented in Table 6.) Skilled leadership is essential in order to fully utilize the available input from knowledgeable persons, often of widely differing backgrounds and interests. While KSIM has been developed and tested to help solve planning problems, its future application depends largely on the willingness of planners to try the procedure and develop the skills which will permit them to incorporate the KSIM technique into their planning process. It is hoped that this document and the on-line availability of the KSIM computer program will encourage such trial and develop such skills in planners.

Table 6 – GUIDELINES FOR A KSIM WORKSHOP

Event:	Discuss the Problem Explain the Technique Meeting 1	Identify & Define Variables Meeting 2	Cross Impact Meeting 3	Refine the Model Meeting 4	Test Alternatives Meeting 5
Time:	2 – 8 hours	2 – 4 hours	4 – 8 hours	4 – 8 hours	4 – 8 hours
Basic Assumption:	Complex systems can be modeled	System variables are bounded There must be a distinct set of limits. (In this procedure these can be set to zero and one)	A variable increases or decreases according to whether the net impact of the other variables is positive or negative	All other things being equal, the larger the variable, the greater the impact on the system	Complex interactions are described by a a looped network of binary interactions
General Comments:	Problem formulation is the most difficult step Distortions are introduced by failing to recognize different levels of organization - be consistent and sensitive to levels of organization - if levels are mixed, plan to compensate A simple procedural example is useful in explaining the KSIM technique However, use with caution Avoid the temptation to make examples elaborate or detailed	An excessive number of variables (more than about nine) does not improve the resolution of the problem and indeed becomes quite cumbersome Explain the concept of S-shaped curves and define all variables in terms of threshold and saturation Danger - by transforming subject concepts into numbers They can acquire metric system emphasis with all the fallacies of interpretation	Requires an experienced leader - encourage discussion yet ensure against authoritarian monologue - Expect definitions to take on more relevant meanings - Be prepared to aggregrate or disaggregate variables - Beware of heavily biased positive or negatives - look for counter forces	The forecasted interactions among variables focuses attention on critical areas Question and understand the output - are the trends reasonable? - are the initial values accurate - scale the impacts - are functional rather than constant relationships necessary? Needs - computer program either remote or on-line - date to scale matrices and verify growth rates	Changes in the state of the system - change initial values - change magnitude of impacts - control growth rates - interventions from outside Change the structure of the system - add or delete a variable - restructure relationships - interventions from within
Group Attitude.	Enthusiasm A technique to tie together and lend weight to intuition	Disillusionment The problem is complex Can it be modeled? How do systems really work?	Group Cohesion Well structured nonauthoritarian method for structuring the problem	Work A good model requires thought and sound data	Mastery A better understanding of the problem and how to utilize KSIM

KSIM ASSUMPTIONS AND MATHEMATICAL FORMULATION *Appendix*

The KSIM mathematics, developed by Dr. Julius Kane of the University of British Columbia, encompasses the following basic assumptions.

(1) System variables are bounded. All variables have a minimum value of zero and a maximum value of one.

(2) A variable increases or decreases according to whether the net impact of the other variables upon it is positive or negative.

(3) Response of a variable to a given impact goes to zero as that variable approaches either bound, threshold or saturation.

(4) Impact of a variable on the system depends upon the size of the variable and the force of the impact.

(5) Complex interactions are described by an array of binary interactions.

Based on these assumptions, a change in the state of a variable is calculated by raising the variable to an exponent. Since variables are bounded above and below, they can be rescaled to range from zero to one. Thus for each variable $x_i(t)$ we have

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

To preserve boundedness, a change in the variable $x_i(t + \Delta t)$ is calculated by

$$(2)\qquad x_i(t + \Delta t) = x_i(t)^P.$$

The exponent $P_i(t)$ is given by

$$(3)\qquad P_i(t) = \frac{1 + \frac{1}{2}\Delta t \sum_{j=1}^{M} \left[\left| \alpha_{ij} x_j + \beta_{ij} \frac{dx_j}{dt} \right| - \left(\alpha_{ij} x_j + \beta_{ij} \frac{dx_j}{dt} \right) \right]}{1 + \frac{1}{2}\Delta t \sum_{j=1}^{M} \left[\left| \alpha_{ij} x_j + \beta_{ij} \frac{dx_j}{dt} \right| + \left(\alpha_{ij} x_j + \beta_{ij} \frac{dx_j}{dt} \right) \right]}$$

Where

α_{ij} are matrix elements giving the impact of x_j on x_i.

β_{ij} are matrix elements giving the impact of the percentage change in x_j, $d(\ln x_j)/dt$, on x_i.

Δt is the time period of one iteration.

While the α_{ij} and β_{ij} are generally constant, they may be functions of the variables x_i and time in a more sophisticated application of KSIM.

The exponent $P_i(t)$ given in Equation (3) can be interpreted as:

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

Thus the exponent is interpreted as the sum of the negative impacts on a variable divided by the positive impacts on the variable. When the negative impacts are greater than the positive ones, the exponent is greater than one, and the variable decreases. Similarly, if $P_i(t)$ is less than one, then the positive impacts are greater than the negative impacts and the variable increases When $P_i(t)$ equals one, the variable is unchanged. Other properties of this formulation become evident when the system of differential equations implied by Equations (2) and (3) as $\Delta t \rightarrow 0$ are examined.

Reader Note. A detailed analysis of the KSIM mathematics has been completed and is available from the Institute for Water Resources The report by B E Suta, entitled "KSIM Theoretical Formulation – A Parametric Analysis," gives the KSIM user a better understanding of the assumptions and inputs and explains exactly how these affect the results. Also, a computer program has been developed to perform the iterative calculations described in this appendix. The program is interactive and can quickly accommodate numerous changes The program does not teach the KSIM technique Rather, it allows planners to examine the behavior of their model and test quickly and easily numerous planning options and interventions. A "KSIM Execution Guide" by P. A. Garza has been reproduced and both the guide and a copy of the program can be obtained from the Institute for Water Resources. The KSIM program is also available for Corps use through the Waterways Experiment Station system at Vicksburg, Mississippi

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