Chapter III

METHODOLOGY FOR FORMULATING THE SYSTEM

The designing of the comprehensive system dynamic model for water resources using remote sensing techniques with special reference to Karamana watershed was proposed to be done with the help of Geographic Information system and system dynamic modeling techniques. The schematic operations are done based on the principles of Spatial and non spatial modeling. For spatial modeling Geographic Information system has been utilized so that the spatial representation of the study area was pre arranged into requisite thematic maps. The attribute data connected with the water resource managements are subjected under the non spatial network comprising of advanced methodologies of system dynamic modeling.

3.1 Geographic Information System (GIS)

GIS has been defined as a computer assisted system for the acquisition, storage, analysis and display of geographic data according to user-defined provisions (Laurini and Thompson, 1992). It has a digital database management system intended to accept large volumes of spatially distributed data from a variety of sources (Jensen and Christensen, 1986). The most powerful characteristics of GIS centre on their ability to evaluate spatial data based on descriptive attributes. The use of GIS software can help to reduce data integration problems caused by the different geographic units to which different data sets are related (Burrough, 1986). GIS allows overlaying of maps with different thematic data (e.g. soil and land use, watershed, district, village maps) and thereby facilitates map integration and analysis. GIS distance modeling makes it possible to assess the interaction of (potential) land uses, and the physical infrastructure and market. It also permits the combination of maps with data generated by models (Bronsveld, et al, 1994). In short, the primary goal of a GIS is take raw data and transform it, via overlay and other
analytical operations, into new information which can support decision-making processes. GIS was pioneered into developing countries during the 1980’s, the key agents of delivery being a variety of UN agencies. The approach adopted in the use of GIS was fundamentally top-down, with ARC/INFO used on mini-computers as the principal schema. As GIS developed, however, more inexpensive systems were introduced using micro-computers, e.g. ILWIS from ITC and IDRISI from Clark University. As these various GIS systems were taken up by both universities and research centers, so a change took place in the application of GIS, with bottom-up approaches being developed, (Taylor, 1991).

The introduction of GIS, whether top-down or bottom-up, has usually come from outside and so far GIS has been only marginal to the solution of development problems. Hence (Taylor, 1991) argues that it is a necessary first step for indigenous scientists to gain a greater degree of knowledge and control of this technology.

Modern GIS technologies utilize digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is converted into a digital medium through the use of a computer-aided design (CAD) program such as AutoCAD and LISCAD, and geo-referencing capabilities. With the wide availability of ortho-rectified imagery (both from satellite and aerial sources), heads-up digitizing is becoming the main avenue through which geographic data is extracted. Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery instead of by the traditional method of tracing the geographic form on a separate digitizing tablet (heads-down digitizing).

3.2 Integration and Coordination of Data from various sources
GIS uses spatio-temporal (space-time) location as the key index variable for all other information. Just as a relational database containing text or numbers can relate many different tables using common key index variables, GIS can relate otherwise unrelated information by using location as the key index variable. The key is the location and/or extent in space-time.

Any variable that can be located spatially, and increasingly also temporally, can referenced using a GIS. Locations or extents in Earth space-time may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, longitude, latitude, and elevation, respectively. These GIS coordinates may represent other quantified systems of temporo-spatial reference (for example, film frame number, stream gage station, highway mile marker, surveyor benchmark, building address, street intersection, entrance gate, water depth sounding, POS or CAD drawing origin/units). Units applied to recorded temporal-spatial data can vary widely (even when using the exact same data, see map projections), but all Earth-based spatial-temporal location and extent references should, ideally, be relatable to one another and ultimately to a "real" physical location or extent in space-time.

Related by accurate spatial information, an incredible variety of real-world and projected past or future data can be analyzed, interpreted and represented to facilitate education and decision making. This key characteristic of GIS has begun to open new avenues of scientific inquiry into behaviors and patterns of previously considered unrelated real-world information.

3.3 Representation of Data
GIS data represents real objects (such as roads, land use, elevation, trees, waterways, etc.) with digital data determining the mix. Real objects can be divided into two abstractions: discrete objects (e.g., a house) and continuous fields (such as rainfall amount, or elevations). Traditionally, there are two broad methods used to store data in a GIS for both kinds of abstractions mapping references: raster images and vector. Points, lines, and polygons are the stuff of mapped location attribute references. A new hybrid method of storing data is that of identifying point clouds, which combine three-dimensional points with RGB information at each point, returning a "3D color image". GIS Thematic maps then are becoming more and more realistically visually descriptive of what they set out to show or determine.

### 3.4 Raster format

A raster data type is, in essence, any type of digital image represented by reducible and enlargeable dynamic grids. Anyone who is familiar with digital photography will recognize the Raster graphics pixel as the tiniest individual grid unit building block of an image, usually not readily identified as an artifact shape until an image is produced on a appreciably large scale. A combination of the pixels making up an image color formation scheme will compose details of an image, as is distinct from the commonly used points, lines, and polygon area location symbols of scalable vector graphics as the basis of the vector model of area attribute rendering. While a digital image is concerned with its output blending together its grid based details as an identifiable representation of reality, in a photograph or art image transferred into a computer, the raster data type will reflect a digitized abstraction of reality dealt with by
grid populating tones or objects, quantities, cojoined or open boundaries, and map relief schemas. Aerial photos are one commonly used form of raster data, with one primary purpose in mind: to display a detailed image on a map area, or for the purposes of rendering its identifiable objects by digitization. Additional raster data sets used by a GIS will contain information regarding elevation, a digital elevation model, or reflectance of a particular wavelength of light, Landsat, or other electromagnetic spectrum indicators.

3.5 Digital Elevation Model (DEM), Map (Image)

Raster data type comprises of rows and columns of cells, with each cell storing a single value. Raster data can be images such as raster images with each pixel or identified Cell containing a color Pixel value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (Red, Green, Blue) colors, colormaps (a mapping between a thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units.

3.6 Vector data Type

In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes such as Polygons, Lines and Points (topology). Different geographical features are expressed by different types of geometry:

3.6.1 Point topology
A simple vector map, using each of the vector elements: points for wells, lines for rivers, and a polygon for the lake. Zero-dimensional points are used for geographical features that can best be expressed by a single point reference in other words, by simple location. Examples include wells, peaks, features of interest, and trailheads. Points convey the least amount of information of these file types. Points can also be used to represent areas when displayed at a small scale. For example, cities on a map of the world might be represented by points rather than polygons. No measurements are possible with point features.

### 3.6.2 Lines or polylines topology

Generally they are represented as arcs. One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines. Again, as with point features, linear features displayed at a small scale will be represented as linear features rather than as a polygon. Line features can measure distance.

### 3.6.3 Polygon Topology

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types. Polygon features can measure perimeter and area.

Each of these geometries is linked to a row in a attribute database that describes their attributes. For example, a database that describes lakes may contain attribute data or relational data such as lake's depth, water quality, pollution level. This information can be used to make a map to describe a particular attribute of the dataset. For example, different colors can represented as the intensity of pollution of lakes. The dimension of the polygon shape represents the geographical area of the area of interest.
Vector data type can be made to enhance the spatial integrity through the application of topology rules such as 'polygons must not overlap'. Vector data can also be used to represent continuously varying phenomena. Contour lines formulated in the maps with regular intervals and Triangulated Irregular Networks (TIN) are used to represent elevation or other continuously changing values. TINs record values at point locations, which are connected by lines to form an irregular mesh of triangles. The face of the triangles represent the terrain surface.

3.7 Advantages and disadvantages

There are some important advantages and disadvantages to using a raster or vector data model to represent reality:

- Raster datasets record a value for all points in the area covered which may require more storage space than representing data in a vector format that can store data only where needed.
- Raster data allows easy implementation of overlay operations, which are more difficult with vector data.
- Vector data can be displayed as vector graphics used on traditional maps, whereas raster data will appear as an image that may have a blocky appearance for object boundaries. (depending on the resolution of the raster file)
- Vector data can be easier to register, scale, and re-project, which can simplify combining vector layers from different sources.

- Vector data is more compatible with relational database environments, where they can be part of a relational table as a normal column and processed using a multitude of operators.

- Vector file sizes are usually smaller than raster data, which can be 10 to 100 times larger than vector data (depending on resolution).

- Vector data is simpler to update and maintain, whereas a raster image will have to be completely reproduced. (Example: a new road is added).

- Vector data allows much more analysis capability, especially for "networks" such as roads, power, rail, telecommunications, etc. (Examples: Best route, largest port, airfields connected to two-lane highways). Raster data will not have all the characteristics of the features it displays.

### 3.8 Non-spatial data or Attribute data

Additional non-spatial data can also be stored along with the spatial data represented by the coordinates of a vector geometry or the position of a raster cell. In vector data, the additional data contains attributes of the feature. For example, a forest inventory polygon may also have an identifier value and information about tree species. In raster data the cell value can store attribute information, but it can also be used as an identifier that can relate to records in another table.
Software is currently being developed to support spatial and non-spatial decision-making, with the solutions to spatial problems being integrated with solutions to non-spatial problems. The end result with these Flexible Spatial Decision-Making Support Systems (FSDSS) is expected to be that non-experts will be able to use GIS, along with spatial criteria, and simply integrate their non-spatial criteria to view solutions to multi-criteria problems. This system is intended to assist decision-making.

3.9 Capturing the Data

Data capture—entering information into the system—consumes much of the time of GIS users. There are various types of methodologies adopted for entering data into a GIS where it is restored in a digital format.

Existing data printed on paper or PET film maps can be digitized or scanned to produce digital data. A digitizer produces vector data as an operator traces points, lines, and polygon boundaries from a map. Scanning a map results in raster data that could be further processed to produce vector data.

Survey data can be started entered into a GIS from digital data collection systems on survey instruments using a technique called Coordinate Geometry (COGO). Positions from a Global Navigation Satellite System (GNSS) like Global Positioning System (GPS), another survey tool, can also be directly entered into a GIS. Current trend is data collection and field mapping carried out directly with field computers (position
from GPS and/or laser rangefinder). New technologies allow to create maps as well as analysis directly in the field, projects are more efficient and mapping is more accurate.

Remotely sensed data also plays an important role in data collection and consist of sensors attached to a platform. Sensors include cameras, digital scanners and LIDAR, while platforms usually consist of aircraft and satellites.

The majority of digital data currently comes from photo interpretation of aerial photographs. Soft copy workstations are used to digitize features directly from stereo pairs of digital photographs. These systems allow data to be captured in two and three dimensions, with elevations measured directly from a stereo pair using principles of photogrammetry. Currently, analog aerial photos are scanned before being entered into a soft copy system, but as high quality digital cameras become cheaper this step will be skipped.

Satellite remote sensing provides another important source of spatial data. Here satellites use different sensor packages to passively measure the reflectance from parts of the electromagnetic spectrum or radio waves that were sent out from an active sensor such as radar. Remote sensing collects raster data that can be further processed using different bands to identify objects and classes of interest, such as land cover.

When data is captured, the user should consider if the data should be captured with either a relative accuracy or absolute accuracy, since this could not only influence how information will be interpreted but also the cost of data capture.
In addition to collecting and entering spatial data, attribute data is also entered into a GIS. For vector data, this includes additional information about the objects represented in the system.

After entering data into a GIS, the data usually requires editing, to remove errors, or further processing. For vector data it must be made "topologically correct" before it can be used for some advanced analysis. For example, in a road network, lines must connect with nodes at an intersection. Errors such as undershoots and overshoots must also be removed. For scanned maps, blemishes on the source map may need to be removed from the resulting raster. For example, a fleck of dirt might connect two lines that should not be connected.

3.10 Conversion of Raster data into Vector format

Data translation can be exercised by a GIS to convert data into various formats. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion.

More advanced data processing can occur with image processing, a technique developed in the late 1960s by NASA and the private sector to provide contrast enhancement, false colour rendering and a variety of other techniques including use of two dimensional Fourier transforms.
Since digital data is collected and stored in various ways, the two data sources may not be entirely compatible. So a GIS must be able to convert geographic data from one structure to another.

### 3.11 Geo-referencing, Projection and Transformation

Base maps which are furnished according to the themes may be in different scales. Map information in a GIS must be manipulated so that it registers, or fits, with information gathered from other maps. Before the digital data can be analyzed, they may have to undergo other manipulations—projection and coordinate conversions, for example—that integrate them into a GIS.

The earth may be represented by various models, each of which may provide a different set of coordinates (e.g., latitude, longitude, elevation) for any given point on the Earth's surface. The simplest model is to assume the earth is a perfect sphere. As more measurements of the earth have accumulated, the models of the earth have become more sophisticated and more accurate.

### 3.12 Spatial analysis with GIS

This is a rapidly changing field, and GIS packages are increasingly including analytical tools as standard built-in facilities or as optional toolsets, add-ins or 'analysts'. In many instances such facilities are provided by the original software suppliers (commercial vendors or collaborative non-commercial development teams), whilst in other cases facilities have been developed and are provided by third parties. Furthermore, many products offer software development kits (SDKs), programming languages and
language support, scripting facilities and/or special interfaces for developing one’s own analytical tools or variants. The website Geospatial Analysis and associated book/ebook attempt to provide a reasonably comprehensive guide to the subject. The impact of these myriad paths to perform spatial analysis create a new dimension to business intelligence termed "spatial intelligence" which, when delivered via intranet, democratizes access to operational sorts not usually privy to this type of information.

3.13 System Modeling

It is difficult to relate wetlands maps to rainfall amounts recorded at different points such as airports, television stations, and high schools. A GIS, however, can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from information points. For example, a GIS can quickly generate a map with isopleth or contour lines that indicate differing amounts of rainfall.

Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlaid and analyzed with any other map in a GIS covering the same area.

Additionally, from a series of three-dimensional points, or digital elevation model, isopleth lines representing elevation contours can be generated, along with slope analysis, shaded relief, and other elevation products. Watersheds can be easily defined for any given reach, by computing all of the areas contiguous and uphill from any given point of interest. Similarly, an expected thalweg of where surface water would want to
travel in intermittent and permanent streams can be computed from elevation data in the GIS.

3.14 Modeling using the concept of Topology

A GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modelling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (what encloses what), and proximity (how close something is to something else).

3.15 Analysing the Networks

If all the factories near a wetland were accidentally to release chemicals into the river at the same time, how long would it take for a damaging amount of pollutant to enter the wetland reserve? A GIS can simulate the routing of materials along a linear network. Values such as slope, speed limit, or pipe diameter can be incorporated into network modeling to represent the flow of the phenomenon more accurately. Network modelling is commonly employed in transportation planning, hydrology modeling, and infrastructure modeling.

3.16. Modeling with the concept of Hydrology

GIS hydrological models can provide a spatial element that other hydrological models lack, with the analysis of variables such as slope, aspect and watershed or catchment area. Terrain analysis is fundamental to hydrology, since water always flows
down a slope. As basic terrain analysis of a DEM involves calculation of slope and aspect, DEMs are very useful for hydrological analysis. Slope and aspect can then be used to determine direction of surface runoff, and hence flow accumulation for the formation of streams, rivers and lakes. Areas of divergent flow can also give a clear indication of the boundaries of a catchment. Once a flow direction and accumulation matrix has been created, queries can be performed that show contributing or dispersal areas at a certain point. More detail can be added to the model, such as terrain roughness, vegetation types and soil types, which can influence infiltration and evapotranspiration rates, and hence influencing surface flow. These extra layers of detail ensures a more accurate model.

### 3.17 Cartographic modeling

An example of use of layers in a GIS application. In this example, the forest cover layer (light green) is at the bottom, with the topographic layer over it. Next up is the stream layer, then the boundary layer, then the road layer. The order is very important in order to properly display the final result. Note that the pond layer was located just below the stream layer, so that a stream line can be seen overlying one of the ponds.

The term "cartographic modeling" was (probably) coined by Dana Tomlin in his PhD dissertation and later in his book which has the term in the title. Cartographic modeling refers to a process where several thematic layers of the same area are produced, processed, and analyzed. Tomlin used raster layers, but the overlay method can be used
more generally. Operations on map layers can be combined into algorithms, and eventually into simulation or optimization models.

### 3.18 Overlay Analysis of Maps

The combination of several spatial datasets (points, lines or polygons) creates a new output vector dataset, visually similar to stacking several maps of the same region. These overlays are similar to mathematical Venn diagram overlays. A union overlay combines the geographic features and attribute tables of both inputs into a single new output. An intersect overlay defines the area where both inputs overlap and retains a set of attribute fields for each. A symmetric difference overlay defines an output area that includes the total area of both inputs except for the overlapping area.

Data extraction is a GIS process similar to vector overlay, though it can be used in either vector or raster data analysis. Rather than combining the properties and features of both datasets, data extraction involves using a "clip" or "mask" to extract the features of one data set that fall within the spatial extent of another dataset.

In raster data analysis, the overlay of datasets is accomplished through a process known as "local operation on multiple rasters" or "map algebra," through a function that combines the values of each raster's matrix. This function may weigh some inputs more than others through use of an "index model" that reflects the influence of various factors upon a geographic phenomenon.

### 3.19 Automated cartography
Digital cartography and GIS both encode spatial relationships in structured formal representations. GIS is used in digital cartography modeling as a (semi)automated process of making maps, so called Automated Cartography. In practice, it can be a subset of a GIS, within which it is equivalent to the stage of visualization, since in most cases not all of the GIS functionality is used. Cartographic products can be either in a digital or in a hardcopy format. Powerful analysis techniques with different data representation can produce high-quality maps within a short time period. The main problem in Automated Cartography is to use a single set of data to produce multiple products at a variety of scales, a technique known as cartographic generalization.

Digital elevation models (DEM), triangulated irregular networks (TIN), edge finding algorithms, Thiessen polygons, Fourier analysis, (weighted) moving averages, inverse distance weighting, kriging, spline, and trend surface analysis are all mathematical methods to produce interpolative data.

3.20 Data output and cartography

Cartography is the design and production of maps, or visual representations of spatial data. The vast majority of modern cartography is done with the help of computers, usually using a GIS but production quality cartography is also achieved by importing layers into a design program to refine it. Most GIS software gives the user substantial control over the appearance of the data.

3.21 Graphic display techniques
Traditional maps are abstractions of the real world, a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of land surface with contour lines or with shaded relief.

Today, graphic display techniques such as shading based on altitude in a GIS can make relationships among map elements visible, heightening one's ability to extract and analyze information. For example, two types of data were combined in a GIS to produce a perspective view of a portion of San Mateo County, California.

- The digital elevation model, consisting of surface elevations recorded on a 30-meter horizontal grid, shows high elevations as white and low elevation as black.

- The accompanying Landsat Thematic Mapper image shows a false-color infrared image looking down at the same area in 30-meter pixels, or picture elements, for the same coordinate points, pixel by pixel, as the elevation information.

GIS was used to register and combine the two images to render the three-dimensional perspective view looking down the San Andreas Fault, using the Thematic Mapper image pixels, but shaded using the elevation of the landforms. The GIS display depends on the viewing point of the observer and time of day of the display, to properly render the shadows created by the sun's rays at that latitude, longitude, and time of day.

3.22 Concept of Attribute Data Model

The rapidity and volume of changes have resulted in less lead time for administrators to analyze changes in their institutions' external environment and to formulate appropriate strategies.
In addition, the risks and uncertainty involved in implementing a particular strategy or set of strategies have intensified. In summary, the turbulence in higher education's external environment challenges the capability of decision makers to effectively anticipate changing conditions.

This phenomenon of rapid environmental shifts led to a recognition among administrators and organizational theorists of the need for a comprehensive approach to institutional planning that emphasizes sensitivity to the effects of environmental shifts on the strategic position of the institution (Ellison, 1977; Cope, 1988). An administrator's analysis of the organization's environment is critical in accurately assessing the opportunities and threats that the environment poses for the institution and in developing the strategic policies necessary to adapt to both internal and external environments.

The conventional planning models are weak in identifying environmental changes and in assessing their organizational impact. In his analysis of the approaches to planning exhibited by American educational institutions, Ziegler (1972) identified two primary assumptions that characterize the weakness of these models: (a) the organization's environment will remain essentially static over time; and (b) the environment is composed of only a few variables that impact education. In essence, the underlying assumption of most current educational planning is that environmental change will be a continuation of the rate and direction of present (and past) trends. These trends are manifested in the "planning assumptions" typically placed in the first part of an institution's strategic or long-range plan. Therefore, many administrators implicitly expect a "surprise-free" future for the institutions. We know, however, that change, not continuation, will be the trend, and the further we go out into the future, the more true this will be. An approach is needed that enables administrators to detect signals of change in all sectors of the environment and to link environmental information to the organization's strategic management (Chaffee, 1985; Levy and Engledow, 1986; McConkey, 1987; Dutton and Duncan, 1987; Hearn, 1988).
Environmental analysis and forecasting are based upon a number of assumptions, among them the following (Boucher and Morrison, 1989):

- The future cannot be predicted, but it can be forecasted probabilistically lacking explicit account of uncertainty.

- Forecasts are virtually certain to be useless or misleading if they do not sweep widely across possible future developments in such areas as demography, values and lifestyles, technology, economics, law and regulation, and institutional change.

- Alternative futures including the "most likely" future are defined primarily by human judgment, creativity, and imagination.

- The aim of defining alternative futures is to try to determine how to create a better future than the one that would materialize if we merely kept doing essentially what is presently being done.

A model based upon assumptions like these is shown in Figure 3.0. Basically, the model states that from our experiences or through environmental scanning we identify issues or concerns that may require attention. These issues/concerns are then defined in terms of their component parts-trends and events. Univariate forecasts of trends and events are generated and subsequently interrelated through cross-impact analysis. The "most likely" future is written in a scenario format from the univariate trend and event forecasts; outlines of alternative scenarios to that future are generated by computer simulations from the cross-impact matrix. In turn, these scenarios stimulate the development of policies appropriate for each scenario. These policies are analyzed for their robustness across scenarios. The purpose of the entire exercise is to derive a final of policies that effectively address the issues and concerns identified in the initial stage of the process. These policies are then implemented in action plans.
3.23 Forecasting

Having defined the trend and event sets, the next step is to forecast subjectively the items in each of these sets over the period of strategic interest (e.g. the next 15 years). For trends, the
likely level over this period is projected. This is an exploratory forecast. It defines our expectation, not our preference. (Normative forecasts define the future as we would like it to be with the focus on developing plans and policies to attain that future.) Similarly, the cumulative probability of each event over the period of interest is estimated, again on the same assumption.

It is important to distinguish between the terms prediction and forecast. Science depends upon theoretical explanation from which predictions can be made. With respect to the future, a prediction is an assertion about how some elements of “the” future will, in fact, materialize. In contrast, a forecast is a probabilistic statement about some element of a possible future. The underlying form of a forecast statement is, "If A occurs, plus some allowance for unknown or unknowable factors, then maybe we can expect B or something very much like B to occur, or at least B will become more or less probable."

A major objective of forecasting is to define alternative futures, not just "most likely" future. The development of alternative futures is central to effective strategic decision-making (Coates, 1985). Since there is no single predictable future organizational strategists need to formulate strategy within the context of alternative futures (Heydinger and Zenter, 1983; Linneman and Klein, 1979). To this end, it is necessary to develop a model that will make it possible to show systematically the interrelationships of the individually forecasted trends and events.

3.24 Cross-Impact Analysis

The essential idea behind a cross-impact model is to define explicitly and completely the pairwise causal connections within a set of forecasted developments. In general, this process involves asking how the prior occurrence of a particular event might affect other events or trends in the set. When these relationships have been specified, it becomes possible to let events
"happen"-either randomly, in accordance with their estimated probability, or in some prearranged way-and then trace out a new, distinct, plausible and internally consistent set of forecasts. This new set represents an: alternative to the comparable forecasts in the "most likely" future (ie., the "expected" future). Many such alternatives can be created. Indeed, if the model is computer-based, the number will be virtually unlimited, given even a small base of trends and events and a short time horizon (eg., the next ten years).

The first published reference to cross-impact analysis occurred in the late 1960s (Gordon, 1968), but the original idea for the technique dates back to 1966, when the co inventors, T. J. Gordon and Olaf Helmer, were developing the game FUTURES for the Kaiser Aluminum Company. In the first serious exploration of this new analytic approach, the thought was to investigate systematically the "cross correlations" among possible future events (and only future events) to determine among other things, if improved probability estimates of these events could be obtained by playing out the cross-impact relationships and, more important if it was possible to model the event-to-event interactions in a way that was useful for purposes of policy analysis (Gordon and Haywood, 1968).

The first of these objectives was soon shown to be illusory, but the second was not, and the development of improved approaches of event-to-event cross-impact analysis proceeded (Gordon, *et.al* 1970), with most of the major technical problems being solved by the early 1970s (Enzer *et.al* 1971).

The next major step in the evolution of cross-impact analysis was to model the interaction of future events and trends. This refinement, first proposed by T. J. Gordon, was implemented in 1971-1972 by Gordon and colleagues at The Futures Group and was called trend impact analysis or TIA (Gordon, 1977). Similar work was under way elsewhere (Helmer, 1972; Boucher, 1976),
but TIA became well established, and it is still in use, despite certain obvious limitations, particularly its failure to include event-to-event interactions.

Two strands of further research then developed independently and more-or-less parallel with the later stages in the creation of TIA. Each was aimed primarily at enabling cross-impact analysis to handle both event-to-event and event-to-trend interactions and to link such a cross-impact modeling capability to more conventional system models, so that developments in the latter could be made responsive to various sequences and combinations of developments in the cross-impact model. One strand led to the joining of cross-impact analysis with a system dynamics model similar to the one pioneered by Jay Forrester and made famous in the first Club of Rome study (Meadows et al., 1972). This line of research—again directed by T. J. Gordon—produced a type of cross-impact model known as probabilistic system dynamics or PSD.

The second strand led to a cross-impact model known as INTERAX (Enzer, 1979), in which the run of a particular path can be interrupted at fixed intervals to allow the user to examine the developments that have already occurred. The user can also examine the likely course of developments over the next interval and can intervene with particular policy actions before the run is resumed. Since the development of INTERAX, which requires the use of a mainframe computer, some work has been done to make cross-impact analysis available on a microcomputer. The Institute for Future Systems Research has developed a simple cross-impact model (Policy Analysis Simulation System- PASS) for the Apple II computer and an expanded version for the IBM AT. A comprehensive cross-impact model, Bravo, was released in mid-1989 by the Bravo Corporation for an IBM AT (Morrison, 1988, July-August). These microcomputer based models greatly enhance the ability to conduct cross-impact analyses and, therefore, to write alternative scenarios much more systematically. Thus the variables associated with the water resources management of the watershed of Karamana river basin have to be analysed with the help this methodology.