EVOLUTION OF A WATER AND POWER DEMAND PROJECTION MODEL FOR SAUDI ARABIA

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ABSTRACT

This paper describes a demand projection effort that evolved over the course of a larger consulting project. The description will focus on the development of a computer simulation model which projects water and power demands for the different regions of Saudi Arabia. It will also be concerned with the development of the proper client/consultant relationship necessary to make the best use of the model's results.

The demand projection effort has been influenced by the interaction of many different and changing factors. Among those factors are the nature of the area being modelled, the client organization's perception of its needs, the modelers' perceptions of the problems to be addressed, and the status of the rest of the consulting project.

The demand model that evolved under the influence of these factors has several unusual attributes. It is a system dynamics model which relies heavily on data collected expressly for it. The model's output is used as the input to a supply optimizing model, which determines the least-cost way to meet the projected demands. And the model's variables are distributed spatially.

The client/consultant relationship has evolved under these same influences. The scope of this relationship has expanded from an emphasis on training to one on more diverse educational activities involving the client's managerial staff.

THE SETTING

The Kingdom of Saudi Arabia is now midway through its second five-year development plan. The amount of new development announced in that plan is much larger than the amount of development previously accomplished in the Kingdom. The development process must deal with many constraints. Among these constraints is the inadequacy of the supply of water and electrical power in the Kingdom.

The groundwater supply in Saudi Arabia is barely adequate for present usage. It will be completely inadequate to satisfy the burgeoning demands of development, especially in the urban areas where the population is concentrated. Surface water is essentially nonexistent. In the face of these shortages, Saudi Arabia has turned to desalination of seawater to help meet the demand for potable water.

The Saline Water Conversion Corporation (SWCC) is the agency of the Saudi government charged with supplying the demands for desalinated water in the Kingdom. To meet these demands, SWCC must have good estimates about where the demands will be, how large they will be, and how fast they will develop. After SWCC obtains these estimates, it must decide where to locate its plants, when to build them, how large they should be, and which of several distinct desalination technologies can be used most economically.

The state of the art of desalination technology itself further complicates the planning problem. The most widely used technology for seawater desalination, multi-stage flash desalination, requires large inputs of heat energy. Because steam generation of electrical power produces large amounts of heat energy, combined operation of power generation facilities and multi-stage flash desalination facilities can produce water and power for a significantly lower cost than separate operation. The extent of the economies realized in such a dual purpose plant depends on the ratio of power production to water production designed into the plant. Consequently, SWCC needs to take into account demands for power as well as water. And in its planning to construct an adequate power and water production system for the lowest cost, SWCC needs to determine not only the size of plants to be constructed, the timing of construction, and the appropriate technology, but also the power-to-water ratio appropriate for each plant.

The planning problem facing SWCC is a complex one, especially in light of the current rapid growth in Saudi Arabia, and resolving it needs the combined efforts of people trained in a variety of disciplines. In June of 1975 SWCC engaged Development Analysis Associates (DAA) to develop the necessary range of analytical tools, and then to transfer to SWCC the ability to use these tools. We at DAA have organized this project into four primary components: 1) the development and conduct of a household survey throughout Saudi Arabia to determine the present needs for water and power, and to gather information on how these needs are changing as development projects proceed; 2) development of a simulation model to project demands for water and power throughout the Kingdom; 3) development of a supply analysis model to minimize the cost of a power and water production system adequate to meet the projected demands; and 4) development of a program to train SWCC personnel in the methodologies of the models so that the models can eventually be used in Saudi Arabia. This organization of the project was one of several significant influences affecting our demand projection effort.

INFLUENCES ON THE EVOLUTION OF THE DEMAND PROJECTION EFFORT

Foremost among the influences shaping the nature of our demand projection effort were the lack of a historical data base and expected fundamental changes in Saudi society. Influences not stemming from the situation in Saudi Arabia included the client's perception of the uses of the project's results, as well as the internal organization of our project.

Very little information is available about the amount of water and power that has been used in Saudi Arabia in the past. This lack of sufficient data makes more usual projection techniques, such as exponential extrapolation of past trends, very difficult to apply. Furthermore, these techniques may be inapplicable because the structure of demand is likely to change in the future as Saudi society changes.

Until very recently, Saudi society has been a traditional one, with the major activities being agriculture and commerce. However, fundamental, pervasive changes are occurring in the nature of Saudi society. During the next two decades Saudi Arabia plans to change from an agrarian and commercial society into one of the leading industrial nations in the world. The transition toward these goals has already begun. Construction of huge industrial complexes has been started. People are flooding into growth centers in order to be a part of this development. They come from the agricultural areas of Saudi Arabia; from the rest of the Middle East; from Africa, East Asia, and Southwest Asia; and even from the Western industrialized countries. Commerce and industry are rapidly expanding in these growth centers, but the supply of goods and services cannot keep up with the demand. Ports have been clogged, delays in the delivery of goods have been inordinately long, severe water shortages have been experienced, blackouts and brownouts have been common. Yet, these physical constraints are expected to be overcome sooner or later, and development is expected to proceed apace.

All these factors will affect the future evolution of water and power demands and have deeply affected our perception of the modelling problem. Properly projecting these demands required use of a technique which takes into account all of these factors and the way that they interact to influence the demands. We therefore chose a dynamic model as the vehicle for our projections. Our realization of the importance of physical constraints to the Saudi development process led us to focus the model on the physical rather than the economic aspects of growth.

The completeness and quality of available data significantly influenced the structure of the projection model at each stage in the evolution of the model. Since the dynamic simulation model required data, particularly for initialization, but very little data was available at the beginning of the project, DAA was obliged to conduct a major household survey of the Kingdom. This survey, which took about two years to complete, collected information principally about patterns of current utility usage, of workforce distribution, and of migration. We were fortunate in being able to obtain, about a year after the project began, census information about the distribution of population.

Another factor that guided the development of the projection effort was the client's changing perception of its own needs. As the client's organization grew, the scope of projects the client could undertake expanded. This expansion in scope is largely responsible for the progression in the area for which the model projected demands, from city to region to zone. In addition to needing an overall planning technique, from time to time the client had more immediate, specific questions that demand projections can help answer. The need to answer these specific questions influenced the focus of our actual projections and our mode of communication with the client rather than the structure of the model itself.

Considerations internal to the project at DAA also had a strong influence on the evolution of the demand projection effort. The principal such influence was the need to meet the requirements of the supply analysis effort, which needs accurate projections of demand for a number of years into the future. The projections should be accurate not only for the time when plants now being planned are put into production, in the early 1980's, but also over an interval long enough to permit the supply analysis model to optimize the construction schedule.

The interval over which we chose to optimize the schedule was the life-cycle of the development triggered by the projects in the second five-year plan. We expect this life-cycle to consist of three periods, beginning in 1975. The first will be characterized by widespread bottlenecks in construction, transportation, and labor as the shock of heavy investment in development projects hits the Kingdom. This period is expected to last about five years. The second will be characterized by rapid development of the industrial base, relatively unhindered by the bottlenecks of the first period. This period is expected to last about ten years. The third period, also expected to last about ten years, will be characterized by the maturation of the private sector once the industrial base is completed. Thus, a planning horizon of about 25 years seemed appropriate for our project. We actually chose a simulation interval of 26 years, from 1974, when the census of Saudi Arabia was taken, to the year 2000, 25 years after the announcement of the second five-year plan.

Developments in the supply analysis model also affected the development of the demand model. As the client's requirements changed, the supply analysis model became more sophisticated and capable of optimizing the construction schedule over an entire region rather than for a single city. This evolution placed on the demand projection model a requirement for more detailed and sophisticated projections.

THE CITY MODEL

The city model was viewed as an attempt to assemble the most important concepts to be used in the final zonal model and was not meant to produce serious projections. The emphasis during this first phase, which lasted about one year, was on exploring both the dynamics of the model and its policy analysis capabilities.

At the beginning of the project the client's immediate concern was to meet the demands of the major growth centers of the Kingdom, particularly Jeddah, Riyadh, and Dammam. The early supply model, which was also in a developmental stage at this time, was designed to optimize over a period of time the supply to a single city. Thus, the demand projection model simulated the demands of a single settlement. In fact, at this stage the demand model consisted of two similar but separate models, one for water and one for power.

The structure of the city model had the most basic elements of later models, but not the detail. The emphasis was on the physical processes of a city, the influence that population movements, business development, construction activities, and the supply of housing and utilities have on each other. Population changes resulted both from natural increase and from migration. Migration was determined by the availability of jobs, houses, and water (or power). The availability of jobs was determined by the volume of business and by the city's population. The rate of growth in the volume of business was determined by an exogenous parameter, the "normal rate of business growth," and by the delay in construction as well as by the availability of water and labor. The availability of houses depended on how many houses there were and on the population. The rate of growth of the housing stock depended on how many people there were, and on the construction delay. The construction delay was determined by the ratio of construction needed to structures already in place. The availability of water depended on the population and on the amounts of groundwater and desalinated water available. The amount of groundwater was constant, and desalination capacity was constructed, after a delay, according to projected demands calculated using a simple exponential extrapolation.

This city model had much the flavor of Jay Forrester's urban dynamics model, except that it did not have an absolute constraint on growth and did have a sector to simulate the supply of utilities. The city model could test a few policies of interest. Among those policies were some over which SWCC had some control, like the planning horizon for building plants, and others which were out of SWCC's control, such as the normal rate of business growth.

At the end of this first modeling stage, preliminary demand projections were sent to the client and comments were invited.

THE REGIONAL MODEL

We had realized from the beginning of the project that analyzing the needs of a single city was not sufficient. There are a number of instances in Saudi Arabia where it is reasonable to consider supplying a number of neighboring cities through one interconnected system. After the first stage of the project, the supply model developed the capability for optimizing the construction schedule of a supply network that could serve an entire region. Projecting the demands independently for each node in the network would not have been reasonable because the cities represented by these nodes compete among themselves and with agricultural areas for workers and water and other scarce resources. We felt that the demand projections should reflect this competition. Therefore, the second stage of the demand projection effort was the development of a model to simulate demands simultaneously over an extended region. This second stage, like the first, lasted for about a year.

A major problem involved in changing a city model into a regional model was representing the geographical distribution of demands over a region. The existence of the array capability in DYNAMO III, the language in which the regional model was written, facilitated solving this problem. One possibility for representing the geographical distribution was to calculate the demands for every settlement in the region. However, that option was unsatisfactory for two reasons. First, for a model as complex as the one we were developing, the separate computation of demands for each settlement would have proved too unwieldy. Second, the results would have been unreliable at such a fine scale because foreseeing all of the exogenous forces that will have an impact on demands is nearly impossible for individual villages, though relatively easy for villages taken as a class. Thus, it was necessary to aggregate the settlements of a region in some manner.

The settlements in the region that we were considering as we developed the regional model, the area around the city of Madinah, could be conveniently divided into three types according to expected growth patterns: the growth centers of Madinah and Yanbu; large towns with 5,000 to 20,000 people; and the remaining villages. Each type of settlement also exhibited distinct characteristics. Consequently, we chose to develop a model simulating growth in three separate settlement types and planned to develop a scheme later for apportioning the demands among the nodes in the supply network. The choice of a constant number of settlement types, rather than use of a more geographical division of settlements as in the supply model, was influenced by the desire to construct one model which could be applicable to many regions. A constant number of settlement types appeared to be more transferable.

In addition to the aggregation into settlement types, the structure of the regional demand model changed considerably from that of the city model. The structural change was dictated both by what we had learned from the earlier model and by our changed perception of what had to be accounted for in projecting growth in Saudi Arabia. This structure has been discussed in more detail in a previous paper (1) but is summarized here.

The model was organized into a number of sectors which simulate closely related sets of activities within a settlement type, plus two sectors which simulate region-wide activities (the material handling and the groundwater sectors). Business activities in the regional model were disaggregated into two sectors: government-sponsored development projects were in one sector, while all private commercial and industrial activities as well as government services were in another. The government development sector was driven by an exogenous schedule of development projects, and in turn triggered the development of the rest of the activities in the settlement type. The private sector developed according to the demands for goods and services which were generated endogenously by the model. This division permitted better representation in the simulation of the government decisions which generate development, while at the same time allowing the forces of supply and demand to determine the rate of growth of the private sector.

The bottlenecks in transportation and construction in Saudi growth centers have been significant constraints to development ever since the beginning of the second five-year plan. In order to simulate these bottlenecks, sectors for construction and material handling were developed. The material handling sector was formulated as a regional sector, since facilities like seaports, airports, roads, and trucks were felt to serve an entire region, not just the immediate area in which they are located.

A demographic sector modelled changes in population. Population was disaggregated into different age groups and economic classes, in order to be able to take into account the rate at which different classes respond to job opportunities and the effects of income on utility demands. The regional model provided for migration among the settlement types according to their relative attractiveness, and migration in and out of the region according to its average attractiveness. The number of influences on attractiveness was increased to include the availabilities of jobs, housing, water, power, and services, as well as the expectations of future growth and the convenience of water and power obtainable through distribution networks. This sector also provided for a class of temporary foreign workers who came to the region to help construct specific facilities, and who were expected to return home when the project was completed.

A housing sector modelled the behavior of the stock of houses. Housing was disaggregated according to economic class of the occupants and according to whether the houses were connected to water and power distribution networks. At this stage no distinction was made between houses connected to water and those connected to power, because we felt the incidence of the two types of connection would be highly correlated.

To investigate the effects of competition for groundwater between agricultural areas and the growth centers, we developed agricultural and groundwater sectors. The agricultural sector modelled the level of agricultural activity in response to government policies and to the availability of water. The groundwater sector was regional in nature because groundwater is shared by all settlement types in the region.

Finally, a utility sector was included, essentially unchanged from that in the city model, to calculate the supply of water and power.

At the end of the second stage, a lengthy technical report was written for the client covering in detail the philosophy and structure of the model and presenting some preliminary projections for the Madinah Region. The client responded to the actual numerical projections, but detailed feedback on the model structure was not expected.

THE ZONAL MODEL

As we were developing and testing the regional model, and as we began to analyze more closely the data from the household survey, we saw the need for more detail at some places in the model and simplification at others, to make the model run more efficiently. At about the same time, SWCC was discussing plans for piping water between regions, while the supply analysis model was becoming more efficient and applicable to more complex networks. So the regional demand model experienced another modification in structure and became a zonal projection model. This change was nowhere near as fundamental as that from the city to the regional model. The change to making projections simultaneously over an entire zone, consisting of several regions, took about a year.

For purposes of planning, we at DAA have divided Saudi Arabia into five planning zones, each of which is composed of from one to four of the Kingdom's 14 administrative regions. To model the demands for a zone, the zone is first divided into "watershed" regions, which do not necessarily correspond to the administrative regions. A watershed region is an area over which groundwater resources are shared. Watershed regions are the "regions" of the zonal model. Each watershed region is divided into a number of demand clusters, which consist of neighboring settlements all lying in the same administrative region. The clusters, which correspond to the demand nodes in the supply network, constitute the finest level of geographical disaggregation modelled by the zonal model.

The concept of settlement type in the regional model became the cluster concept in the zonal model, except that a region in the zonal model could have any number of clusters whereas a region in the regional model was required to be divided into three settlement types. Two considerations prompted this reinterpretation. First, the supply model required a geographical distribution of demands, which the settlement types of the regional model did not provide. We did in fact develop a scheme for apportioning the demands of the settlement types among the nodes of the supply network. However, we soon realized that any such scheme would be cumbersome and would not be able to capture the competition among clusters for scarce resources, a feature that was among the main strengths of the regional demand model. Second, we had developed a procedure for automatically expanding a basic model into one capable of dealing with any number of regions and clusters. This procedure freed us from the constraint that all regions should have the same three settlement types, as in the regional model.

We had learned from testing the regional model and from analyzing our household survey about the importance of various details in the model. This knowledge allowed us to simplify the structure of the zonal model. The disaggregation of the population into age groups in the regional model did not significantly affect the demand projections, because the relative sizes of the groups did not change much in the simulation. Similarly, different economic classes did not evidence demand patterns sufficiently different to justify disaggregation into upper and lower income levels. Also, information from the survey on actual income levels was sketchy for a large part of the population. So those distinctions in the regional model were eliminated in the zonal model.

Other observations from our household survey prompted us to add more structure. The main such change resulted from the observation that connections of houses to water and power distribution networks were not highly correlated, but that the distinction between connected and unconnected houses made a significant difference in per capita demand. Therefore, we reorganized the housing sector so that houses were disaggregated according to both types of connections rather than a combined measure of connection, and not according to socioeconomic class of the occupants. We also found that our data on workforce distribution among the various sectors was our best source of information for determining the number of workers needed to do a given job, and we incorporated that knowledge into the model's structure. The survey results also verified, as we expected, that the availability of jobs was the main determinant of migration.

Through the date of this writing, the zonal model has been used to project demands for two entire zones and for two administrative regions in another zone. Reports have been sent to the client on these projections. The client has requested information on the implications of the projections for desalination plant design parameters, such as the power-to-water ratio. This request has prompted us to shift our emphasis from model development to communication of results and of the potentials of the model, directed toward key users in the client organization.

FUTURE DIRECTIONS

A number of changes can be foreseen in the future activities of our demand projection effort, as the demand model passes from the development into the implementation phase. We do not anticipate in the future changes to the model structure on the same scale as those of the last two years. A number of other issues will occupy our attention.

The question of validation of the model naturally arises. In view of the absence of formal validation procedures, the best tests of validity of the model will be the internal consistency of the entire fabric of the simulations and their consistency with what data are available. The model now seems to perform well against these standards, but as data increase in quantity and reliability in the coming years, we expect that numerical validation of the model will become a significant part of our activity.

The question of the ultimate limits of the Kingdom's development has been raised by the client. The zonal model is not designed to handle such constraints to long-term development; it is oriented to simulating growth in response to exogenous investments in areas which have the capacity to grow. In order to address the question of ultimate limits, DAA has begun to develop a national economic model of Saudi Arabia which can focus on issues involved in the long-term development of the Kingdom, taking into account such factors as depletion of the oil, various industrialization, educational, and agricultural policies, and the possibility of overcrowding and undesirable social change due to large numbers of foreigners. This national model will be run independently of the zonal model, and its output will be used to provide input and suggest structural changes to the zonal model.

We also expect to be involved in the future with suggesting to the client the range of valid uses of our demand projection model beyond simply projecting demands. This effort will concentrate principally on the model's policy evaluation capability, for example, its ability to show the effect of desalination policies on the agricultural areas of a zone or explore the implications for an area of a range of proposed development projects, particularly their effects on the need for desalination and generation capacity. This emphasis results from the realization that simply training the client's personnel to run the model will not ensure the usefulness of the model to the organization. Capturing the interest of decisionmakers and showing them how the model can be of use within their organization is equally important.

CONCLUSION

The development of this implementation-oriented simulation model passed through a number of stages. Some of these stages were clearly developmental, designed for learning rather than for implementing the model. The character of each stage was determined by the changing perceptions both of the modelers and of the client regarding the problem being addressed, by the requirements imposed by the progress of the total project, and by our increasing awareness, gained through analysis of our household survey, of some of the realities influencing water and power demands.

BIBLIOGRAPHY

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