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CONCEPTUAL DESIGN OF A GEOTHERMAL SITE
DEVELOPMENT FORECASTING SYSTEM

By
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March 1980

Work Performed Under Contract No. AC01-77ET28505

The Mitre Corporation
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U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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MTR-80W72

Sponsor: Division of Geothermal Energy/
Department of Energy
Contract No.: EG-77-CO1-4014

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ABSTRACT

A site development forecasting system has been designed in response to the Department of Energy, Division of Geothermal Energy's need to monitor and forecast the development of specific geothermal resource sites for electrical power generation and direct heat applications. The system is comprised of customized software, a site development status data base, and a set of complex geothermal project development schedules. The system would use site-specific development status information obtained from the Geothermal Progress Monitor and other data derived from economic and market penetration studies to produce reports on the rates of geothermal energy development, federal agency manpower requirements to ensure these developments, and capital expenditures and technical/laborer manpower required to achieve these developments.

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EXECUTIVE SUMMARY

The Department of Energy (DOE) is interested in developing a computer-based system to aid in monitoring geothermal electric plant development and to anticipate the manpower staffing levels required for executing the federal actions that must take place before and during geothermal power plant construction. The purpose of this study is to review the status of previous DOE-sponsored efforts in this area and to present a recommended design which will result in an operational system.

A system for monitoring geothermal electric plant developments, based upon a generalized Project Management System (PMS) software package, was designed by WAPORA, Inc. and operated by Auerbach Associates, Inc. until February 1979 when MITRE was tasked to undertake this analysis. A number of deficiencies, principally related to the inability of a generalized software package to accommodate the specific monitoring needs, became evident as MITRE attempted to operate and then modify the system. These deficiencies are enumerated in this report:

- Lack of specific defined purposes for the system
- Lack of documentation
- Inefficient use of software package
- Inefficient system structure (network configuration)
- Low credibility of system parameters such as activity duration and manpower assignment.

Following the review of previous efforts and a discussion of the needs for monitoring and forecasting geothermal electric and direct heat developments, a design is presented which, when implemented, will result in an operational and useful system. The main feature of this design is the simplification of complex schedules through the use of large blocks of activities (hammocks) which terminate in major development milestones such as: land leased, plant construction started, etc. Furthermore, through the use of relational data base concepts, this system is capable of supporting analyses down to the level of individual permitting actions.

1.0 INTRODUCTION

1.1 General

In February 1979, DOE's Division of Geothermal Resource Management (DGRM) tasked MITRE to detect and, if possible, resolve the deficiencies that were exhibited by its current computer-based Project Management System (PMS). This system, using activity networks developed by WAPORA, Inc. and a generalized scheduling software package (PROJECT/2), developed by Auerbach Associates, Inc., was intended to provide DGRM with information pertaining to the current status and forecasts of schedules and manpower requirements for geothermal electric power plant installations at the major U.S. geothermal prospects. The system's difficulties were manifested by the system's inability to produce realistic outputs, and were based on massive data input requirements to an overly detailed and unforgiving software package.

1.2 Purpose of This Study

The purpose of this study was:

- To determine if the existing components and procedures of the PMS, as prepared and configured by the initial contractor, could be improved sufficiently to achieve the objectives of the geothermal electric plant PMS concept, or,
- If it appeared that those components and procedures could not be made fully operational, then to determine what alternative configurations, components, and procedures might suffice to achieve a working PMS.

1.3 Scope of This Study

This study covers the following areas, some of which were evident at the outset and others, of necessity, evolving as the work progressed:

- A review of the developmental history of the PMS to determine why attempts to exercise the system met with difficulties. This review focused on:
 - The geothermal electric plant development networks and schedules, as formulated by WAPORA, Inc.,
 - The PMS software package (PROJECT/2) implemented by Auerbach Associates, Inc. and operated by Boeing Computer Services, and
 - The information provided by DOE field offices on the status of power plant development at specific sites.
- Attempts by MITRE to operate the PMS system to generate the schedule and manpower requirements reports that the system was supposed to be capable of generating.
- Description of the fundamental limitations of the system components and the general difficulties of trying to force a generalized software package to conform to some very specific requirements.
- Definition of altered goals and requirements for a computer-based development and forecasting system.
- Description of an approach for achieving these goals through a more versatile system design better suited to DOE's requirements.

2.0 SYSTEM OVERVIEW

2.1 System Objectives

The development of a strong technical and economic information base that will be capable of providing critical inputs to U.S. geothermal energy policies is a major goal of the DOE Division of Geothermal Energy (DGE) geothermal commercialization program. The site development forecasting effort, based upon the results of previous work and subsequent guidance from DGE, will enable DGE to meet its goals through the accomplishment of the following objectives:

- Implementation and operation of a computer-based site-specific status assessment and forecasting system that will allow DGE to generate critical planning inputs for geothermal commercialization activities and projections of future geothermal energy utilization, based on what is known about the geothermal resource base, the status of geothermal development at specific sites, and the technology and economics of geothermal energy utilization.
- Producing from the system the following important outputs:
 - Statements of the rate at which geothermal energy can be developed, given the best current understanding of the advantages for and constraints to developing geothermal specific sites.
 - Estimates of the amount of manpower needed in 1981-2000 in specific federal agency offices to ensure that federal manpower requirements will not delay geothermal development.
 - Capital funds and technical/laborer manpower needed in 1981-2000 for geothermal energy construction.
 - Sensitivity analyses of how much geothermal energy could be developed if the capital and manpower requirements are maintained at only current levels of investment.
 - Detection and estimation of the time and cost impacts of barriers to development and the impacts of alternative actions to surmount these barriers.

2.2 General Design Strategy

In order to meet the system objectives, a design strategy was selected which relies upon existing mechanisms to obtain the required status and forecasting information. These mechanisms are principally centered in the Geothermal Progress Monitor (GPM), a national-level system for obtaining, analyzing and disseminating information pertaining to geothermal energy utilization⁽¹⁾. The relationship between the site development forecasting system and the GPM is shown graphically in Figure 2-1.

The data are to be obtained on a site-specific basis and will consist of actual status information and planning information. These data will be used in simplified generic development schedules synthesized from an analysis of actual schedules for all currently known applications (see Section 6.2). Using actual reported data supplemented by generic schedule data, the site development forecasting system will be able to determine an estimated completion date and cost from a given start date or any point thereafter, or will be able to trace a schedule in reverse from a desired completion date to a required start date. In either mode, the system will have the capability of scheduling activities for each site and obtaining sums of manpower requirements and costs across sites on a year-by-year basis.

In addition, the system will have the capability to account for the effects of various barriers, on a generic basis, on all site developments for which the barriers apply. That is, an institutional

FIGURE 2-1
RELATIONSHIP BETWEEN THE SITE DEVELOPMENT FORECASTING
SYSTEM AND THE GEOTHERMAL PROGRESS MONITOR

barrier such as the suspension of development pending the acceptance of hydrogen sulfide abatement procedures, or a technical barrier such as the suspension of development pending the successful demonstration of a binary cycle power plant, would be imposed uniformly upon all sites affected by each barrier.

2.3 Definition of Terms

The word "site" has been much used in the geothermal community to designate places where geothermal energy is or might be available and used. There is much ambiguity in this term. In some cases, "site" has been used for a multi-county region. In others, "site" designates the location of a geothermal plant.

This confusion is understandable, given that our current knowledge of geothermal potential and location varies markedly both between states and within states. However, for purposes of analytical and communicative clarity, the following distinctions regarding geothermal resource areas are made:

- "State" - The state in which a known or suspected geothermal resource is located. When a named geothermal resource straddles state boundaries, it is designated as more than one resource. This is necessary because differences in state laws and permitting processes will require different development schedules and monitoring processes.
- "Region" - A multi-county area within a state where a suspected or known geothermal resource is located. The Geysers, Imperial Valley, and Washington Cascade Range are examples of regions. This level of aggregation must be available to handle information and projections about inferred resources.

- "Prospect" - Any subdivision of a region, or group of sites (see below), where it is certain or appears likely that a geothermal field will have to be unitized before geothermal fluid production may begin. Most of the KGRAs (Known Geothermal Resource Areas, as designated by the federal land permitting regulations) and other known electric sites detailed in USGS Circular 790(2) are designated as prospects. In addition, other more recently identified resources that have estimated capacities of less than 500 MWe for 30 years are designated as "prospects".
- "Site" - The location of a single hydrothermal electric or direct heat plant and the well fields that serve it. Sites are designated within each prospect according to numbers assigned by the geothermal industry. For example, 36 sites have been numbered for The Geysers and are referred to as "units" by the industry. By the end of 1979, 13 of these were on line, while many are only in the earliest stages of preliminary planning.

3.0 BACKGROUND

3.1 System Development History

The federal government has been studying and promoting the use of geothermal energy since at least 1970. While much has been learned, and much technical and commercialization progress has been made, there is today no integrated source for rapid answers to questions about the size of the U.S. geothermal industry, the rate at which the U.S. geothermal resource is most likely to be developed, and the impacts which various government strategies are most likely to have on geothermal energy development in the next twenty years.

The available forecasts of geothermal development for the 1980-2000 period have been based on selective subsets of the available information. There is no single forecast that has integrated all of the following:

- Location of the resource,
- Current demand and its anticipated growth,
- Current geothermal technology costs,
- Site-specific progress to date,
- Current and possible future financial incentives,
- Delay-causing impacts of various regulatory processes.

Also, no major forecasting system has been developed in a manner that can support continuous updating.

The development of geothermal resources for hydrothermal electric and direct heat applications generally entails long-running

complex programs involving the interactions of individuals, corporations, and local, state, and federal government agencies. Particularly in the case of hydrothermal electric developments, where the time between leasing the land and start-up of the first generating station is typically 8-15 years, unexpected and undue delays represent significant increases in costs and risks. However, through monitoring and management of geothermal developments at the federal level, many potential schedule disruptions may be identified, anticipated, and resolved prior to their actual occurrence. In order to maintain a high degree of awareness and an appropriate level of control in the arena of expanding geothermal activity, which currently includes over 50 hydrothermal electric and hundreds of direct heat prospects, DGE must acquire a workable geothermal site development forecasting system.

The initial concept of the geothermal PMS was that a commercial project management system software package, a set of standardized federal activity networks and schedules, and data about geothermal electric plant development plans and status could be combined to project the levels required for various activities.

In 1976 MITRE was asked by DGE to develop system concepts for monitoring the development and utilization of geothermal energy in the U.S. The results of this study⁽³⁾ suggested that Program Evaluation and Review Technique/Critical Path Method (PERT/CPM) approaches could be used simultaneously to track and assort incoming

site status information and project future schedule dates for major events at specific sites. In 1977 DGE initiated development of such a system, under the concept that an existing project management system (PMS) scheduling software package (PROJECT/2), a set of standardized activity networks and schedules, and data from federal permitting agencies about hydrothermal electric site development plans and status could be combined to adequately forecast hydrothermal electric site installations.

Auerbach Associates, Inc. implemented the PERT/CPM-oriented PROJECT/2 software package between 1977 and 1978. Meanwhile, WAPORA, Inc. developed a set of six generic activity networks representative of hydrothermal electric site developments, based upon a study of actual schedules, and in particular, the time needed to process required federal leasing and permitting actions. One of these networks is given in Figure 3-1. In 1978, using the WAPORA networks and data obtained from DOE field offices, Auerbach attempted to exercise the PROJECT/2 system on a problem set consisting of 3,635 activities representing 153 hydrothermal electric sites at 28 different prospects. This and subsequent attempts to obtain meaningful results from the "developmental" PROJECT/2 system met with no success.

In early 1979, DGRM requested MITRE to detect and, if possible, to resolve the deficiencies in this system. If it appeared that the existing system could not be made fully operational, MITRE was to recommend alternatives to achieve a working system. Pursuant to this request, MITRE's analysis consisted of the following major steps:

FIGURE 3-1
INITIAL DEVELOPMENT/NON-COMPETITIVE LEASING/U.S.
FOREST SERVICE LANDS
(WAPORA, INC.)

* OR BLM, Depending on Size

FIGURE 3-1
INITIAL DEVELOPMENT/NON-COMPETITIVE LEASING/U.S.
FOREST SERVICE LANDS
(WAPORA, INC.)
(CONTINUED)

- Study and examination of the existing components of the PMS to determine why previous attempts to exercise the system met with difficulties. These components included the PROJECT/2 software, the WAPORA networks, and the status information provided by the DOE field offices.
- Attempts to operate the PMS to generate the desired schedule and resource requirements reports.
- Attempts to enter newly collected electric plant development status data in order to update the existing schedules.
- Altering certain network characteristics and constraints in an attempt to get the PMS to accept status updates.
- Understanding some fundamental limitations of the present system components and recommending how these might be remedied.

3.2 Findings and Conclusions

MITRE reported the results of the first phase of its PMS analysis⁽⁴⁾ including the following major findings:

- PROJECT/2:
 - No procedures are available for simple network changes
 - Incomplete data causes generation of erroneous schedules
 - Software and user documentation is inadequate
 - Software is inefficient and costly to operate
- Data Base:
 - Some sites did not follow their networks
 - Networks are large and difficult to handle
 - Most data were not received in processable form
 - Previous data often conflicted with latest information.

Following this analysis, MITRE undertook a two-part evaluation of 14 other PMS software packages. In the first part of this

evaluation, these packages were reviewed in regard to the following considerations:

- Network representation (ability to accommodate geothermal site development projects).
- Ease of use, particularly in regard to input data preparation.
- Flexibility in network descriptions and economic calculations.
- Special package features and documentation.
- Costs including purchase/rental and maintenance, and the use of non-MITRE computer facilities if required.

Twelve of these 14 packages were eliminated from further consideration principally on the bases of network representation, flexibility and/or costs (see Table 3-1). Although each of the two remaining packages, Control Data Corporation's PROPLAN and IBM's MINIPERT, were preferred to PROJECT/2, neither one met all of the requirements described in Section 2.0 (System Overview) above.

Inasmuch as these two packages were the most promising of those considered, as the second part of its evaluation, MITRE examined several alternative schemes for using these packages alone and in combination to meet the system requirements. However, even the most promising of these alternatives, depicted in Figure 3-2, required the production of several programs to perform preprocessing, input re-formatting and other utility functions. Thus it was determined that none of the commercially available PMS packages, designed mainly for short-term in-house projects, were capable of adequately representing

TABLE 3-1

PMS SOFTWARE PACKAGES NOT SUITABLE FOR
GEOTHERMAL SITE DEVELOPMENT FORECASTING USE

PACKAGE	VENDOR	AREA OF DEFICIENCY		
		NETWORK REPRESENTATION	FLEXI- BILITY	COSTS
N-5000	NICHOLS & CO.	X		
PAC II	INTERNATIONAL SYSTEMS, INC.	X	X	
FERT COST	IBM	X	X	
PLAN CODE	IBM	X		
PLANNING SYSTEMS GENERATOR II	IBM	X		
FMS IV	IBM			X
PROJACS	IBM	X		
PROJECT EVALUATION & CONTROL SYSTEM	IBM	X		
PROJECT MANAGER	MANAGEMENT SYSTEMS PROGRAMMING, INC.	X		
PROJECT MONITOR	PROGRAM PRODUCTS	X		
QUICK-TECH	QUALITY DATA PRODUCTS, INC.	X	X	
SPECTRUM-1	J. TOELLNER & ASSOC.	X

FIGURE 3-2
AN ALTERNATIVE DATA PROCESSING SCHEME FOR SITE
DEVELOPMENT FORECASTING

actual geothermal development projects which are characteristically of long duration and involve many inter-organizational relationships. Therefore, it is concluded that a customized rather than a commercially available PMS package is required in order to meet the system requirements.

4.0 SYSTEM REQUIREMENTS

Monitoring and forecasting geothermal site developments requires a fairly sophisticated analytical treatment, especially for hydrothermal electric applications where a large number of prospects are in various stages of their complex development processes, ranging from pre-exploration activities to fully operational power generation. The basic operating features of a site development forecasting system are:

- The data required for its operation should be minimal and be easily and quickly obtained periodically or as available.
- The system should be easy to operate, particularly in regard to inputting data, specifying operations or analyses to be performed, and selecting outputs.
- The reports produced by the system should be responsive to DGE's requirements and be presented in acceptable formats.

As a result of the findings discussed above (Section 3.2), the system operational and reporting requirements have been redefined as follows⁽⁴⁾:

- Operational capabilities:
 - Represent about 150 hydrothermal electric sites in 50 prospects
 - Be expandable to 400 electric sites and 500 to 1000 direct heat applications
 - Derive initial year when power could come on line from site-specific analyses, known plans, or actual completions
 - Simplify generic networks to include only about 12 elements
 - Obtain input data through the Geothermal Progress Monitor
 - Basic time unit to be not less than 3 months

- Software to be as simple as possible
- Reporting capabilities:
 - Generate federal agency manpower needs
 - Generate industrial capital needs in current dollars
 - Generate reports for monitoring status for sites and prospects
 - Print networks for sites and prospects including required and actual dates and key milestones
 - Capability to levelize resources is not required
 - Ability to track Bureau of Land Management and U.S. Forest Service leasing processes is not required.

5.0 APPROACH

In consideration of the forecasting system's need to simultaneously keep track of ultimately hundreds of hydrothermal electric and direct heat projects in various stages of development and to produce a variety of reports on status and projections, an automated capability is clearly indicated. Because the various geothermal development projects each span a number of years, include the activities of a number of governmental and private-sector organizations, and are not considered "well-behaved" in an analytical sense, the forecasting system design must differ from the classical PERT/CPM approaches.

At the core of a forecasting system of the type under consideration is the handling of the fairly complex geothermal project development schedules. Generally speaking, a network is a quantified representation of a project schedule from start to finish and is composed of distinct but not necessarily unique activities. Each activity describes a basic unit of work or progress, contributed to by one or more organizational entities, and terminates in an event. Attributes of activities, in addition to contributing organizations, include overall duration, manpower utilization, and costs. Activities may occur sequentially or simultaneously, depending upon the nature of the schedule and the availability of resources to perform the work required. The activities spanning two or more events in a network may be aggregated into a hammock, a technique which simplifies networks and promotes broad rather than fine-grained analysis. Figure 5-1 presents an example of the use of these concepts.

FIGURE 5-1
SCHEDULING CONCEPTS

The significant differences in various approaches to forecasting systems occur in the ways in which actual or generic project schedules are represented as networks and in the methods used to analyze these networks. It is these differences and their relationships to the program objectives that distinguish successful approaches from unsuccessful ones. As a particular case in point, the first approach attempted in the solution to this forecasting problem was the application of an existing PERT/CPM software package. As discussed above, although contributed to by other factors, this approach was virtually destined to fail principally because the fine-grained analytical capabilities of this class of software packages could not resolve conflicts in data nor handle generic impacts across multiple sites.

Monitoring and forecasting the development of direct heat applications will be significantly different than hydrothermal electric applications because direct heat projects will, on the average, be much smaller, more widely distributed geographically, and may require only local small-scale industrial expertise to develop. The use of geothermal resources in Boise, ID; Reno, NV; and Klamath Falls, OR for residential and small scale commercial space heating using 300 foot wells and \$5000 systems installed by local water well drillers and plumbers suggests that many small-sized direct heat developments may not be detected by the existing information gathering system. Larger-scale installations, such as integrated direct heating systems and moderate- to large-scale industrial process direct heat uses will

be more visible and easy to track through monitoring of permitting processes and the general knowledge of the engineering and construction community. These larger-scale applications are amenable to monitoring procedures similar to those that will be used for hydrothermal electric applications, but may present additional tracking problems because of reduced public visibility relative to that of projects constructed by regulated electric utilities.

6.0 SYSTEM DESIGN

6.1 General

The principal features of this alternative system design are modularity and flexibility. Modularity enables the basic system to be assembled, tested, and operated relatively quickly and permits the incorporation of additional or more complex capabilities as both the design plan and experience may dictate. Modularity also promotes flexibility in system modification as well as in operation. Thus, a properly structured system of this type enables the user to select from among a menu of standardized procedures and reports as well as to customize the operations through particular data base, module, procedure, and report specification.

6.2 Networks

Networks used in the site development forecasting system are generated automatically by selecting generic schedules, supplying actual schedules of field activities, or combining generic schedules with actual schedules to fill in gaps. The term "schedule" is used to refer to the development of a specific plant (site) whereas "scenario" is used to refer to the sequence of multi-site developments at a prospect.

Schedules will be primarily configured to match permitting processes and field development/plant construction processes because these are the activities that determine most of the timing relationships involved in field development. The permitting sections of the

schedules should be site-specific, but may start from broad generic scenarios that are applicable to specific land ownership (private, state, federal) and state location.

The field development and plant construction time and resource requirements will be drawn from previous MITRE⁽³⁾ and Bechtel⁽⁶⁾ estimates. Federal and state manpower resource requirements will initially be those developed by WAPORA⁽⁷⁾. These manpower resource requirement estimates will have to be updated as the U.S. Forest Service and the Bureau of Land Management alter their pre-lease environmental assessments to focus on leasing for exploratory drilling rather than on power plant construction. The system will have the capability to accept, replace, and utilize date, elapsed time, manpower and cost values obtained from a number of sources.

Certain key milestones cut across all sites for certain plant types. For example, a System Development Corporation study⁽⁸⁾ cited the absence of a demonstrated binary cycle plant as the key problem in the ability of San Diego Gas and Electric to obtain full financing for its 50 MWe binary cycle plant at Heber, California. Thus it seems reasonable to assume that all sites for which binary plants are the most feasible must be projected as "on hold" until this technology is satisfactorily demonstrated in an operational setting.

In this instance, a special activity titled "50 MWe binary plant demonstrated" may have to be inserted in the schedules for binary design sites. To attain a reasonable degree of realism, this activity

should be inserted in different places in different schedules, for industry may hold up all further actions at these sites until this activity is completed, regardless of the current status at each site.

One of the important findings of the Project Management System study⁽³⁾ was that the networks employed were overly complex and were not easily supplied with their requisite status data at appropriate points in time. To overcome these difficulties and to satisfy DGE's requirements, the generic networks developed by WAPORA should be studied and revised into sets of networks consisting of approximately 7 to 12 hammocks linking major milestones. The hammocks should include those activities which, at their completion, lead to a significant event or milestone such as:

- Leasing Completed
- Permitting Completed
- Exploration Finished
- Feasibility Study Completed
- Environmental Statements Approved
- Investment Commitment Made
- Design Completed
- Certification Completed
- Drilling Completed
- Construction Completed.

The individual activities, their participants, and the events they lead to within the hammocks, should be represented separately

from the networks and can, if necessary, be analyzed at their own levels, including the use of PERT/CPM techniques. The relationships between hammocks and activities within a network are depicted in Figure 6-1 which typifies, say, the development of a three-site hydrothermal electric prospect. Note that hammocks H_j and H_{j+1} appear twice and can be thought of as two standardized development phases for all sites after the first. Note also that activities A_4 and A_7 each appear in the expanded layouts of hammocks H_1 and H_2 . Activity A_4 may represent a drilling program performed by one organization and activity A_7 may represent a review process by another organization. The implication of the capabilities to incorporate multiple activity and hammock representations in the same problem set is that the need to input redundant descriptive information is minimized.

6.3 Data Base

The data base that supports the forecasting system consists of three sections: schedule building blocks, site status reports, and supplemental information. The major feature of this data base design is that the files contained within the sections are relational. That is, each file is composed of records which contain unique information plus references (pointers) to records in other files containing more general information. For example, a hammock record may contain its own unique identifier, characteristics data including duration and levels of effort, and the identifiers (pointers) of the specific

FIGURE 6-1
RELATIONSHIPS BETWEEN HAMMOCKS AND ACTIVITIES IN
A NETWORK

activities which are contained within the hammock and whose details are contained in the designated activity records.

The main advantage of the relational data base approach is that, for a small increase in processing costs, data base flexibility is maximized and data redundancy is minimized, which results in a large reduction in data base storage and editing costs.

The schedule building block section consists of three principal files corresponding to the three principal levels of scheduling aggregation: networks, hammocks, and activities. These files will be built based upon the results of studying generic networks and may be added to when new networks are found or postulated, or existing networks are modified or extended. The actual process of producing time-related schedules and performing schedule-dependent analyses will be controlled through the software capabilities described below in which activities may be combined into hammocks, hammocks into networks, and even networks into super networks (applicable to developments on a regional or state basis) utilizing the pointers contained within the appropriate file records. At this early stage of system development, all of the feasible alternatives related to record content and file manipulations have obviously not been fully considered. Thus, this discussion is indicative of the general approach rather than a description of the finalized system design.

The network file contains one record for each uniquely described schedule. Similar networks which may differ by only one hammock are

considered as separate entities. Each network record contains identifying characteristics, including a network code and title, and relational information. Network characteristics generally consist of aggregated hammock data and include total network duration and total required manpower by organization. The relational information consists of one subrecord for each hammock in the network and contains the hammock identifying code as well as the codes for the preceeding and succeeding hammocks. The hammock and activity files are structured in the same manner as the network file. Table 6-1 contains examples of these three files.

The site status section contains data pertaining to the occurrence of events on a site by site basis. Each record contains site identifying information (site code, title, etc.) and one subrecord for each event occurrence which includes the event code, the date of occurrence, and the planned occurrence date. The date of occurrence may either be provided via status inputs to the forecasting system or be generated by running the scheduling portion of the forecasting system. The latter dates, if included in a site status record (a user option), would include a flag (say an asterisk) denoting that the date was calculated rather than reported. Planned occurrence dates are predictions by developers, utilities, and governmental organizations obtained from the field via status reports. Events reported in the status file may be at the activity level or higher. Only those events pertinent to the analysis being performed are

TABLE 6-1

EXAMPLE OF SCHEDULE BUILDING BLOCK FILES

INFORMATION TYPE	ENTRIES IN FILE		
	NETWORK	HAMMOCK	ACTIVITY
IE CODE ID TITLE	N 001 USFS - NONCOMPET	H 012 DRILLING PERMITS	A 067 PLANT SITING
DURATION	12.25 YEARS	4.5 YEARS	0.5 YEARS
ORG ID1, MANMONTHS	USFS, 5	USFS, 2	USFS, 0.5
ORG ID2, MANMONTHS	ELM, 0.5	USGS, 1	USGS, 0.3
ORG ID3, MANMONTHS	USGS, 4	STATE, 0.5	STATE, 1
ORG ID4, MANMONTHS	STATE, 2	CCOUNTY, 0.25	COUNTY, 0.5
ORG ID5, MANMONTHS	COUNTY, 1	*	*
INSTANT UNIT ID	H 012	A 103	*
PRESECESSOR ID	H 009	A 065	*
SUCCESSOR ID	H 021	A 082	*

considered by the software package (see Section 6.4). The information contained in the status file is related to the other files by the site identification code.

The supplemental data section includes a prospects file, organization file, and other files necessary to the main processing functions of the forecasting system. The prospects file contains one record for each geothermal resource prospect. In addition to the identifying information (prospect code, title, etc.), each record contains a characteristics section (geological data, fluid data, resource capacity estimates, etc.) and a subrecord containing the site identification code for each site. The organization file includes identifying information and subrecords for each year in which the organization staffing level is projected to change, including the year of change and the new staff level.

Figure 6-2 displays the principal files of the forecasting system data base and their common relational linkages. Other linkages not depicted, such as between the status file and the prospect file via site identification code, are certainly possible but are not as immediately useful for analytic purposes as those shown. These linkages will be used to verify data being added to the data base, such as checking the hammock and network membership of an event report being added to the status file.

6.4 Validation

The vast majority of the status and projection data input to the forecasting system will be obtained through the GPM and from the

FIGURE 6-2
DATA BASE RELATIONAL FILES

outputs of various predictive models such as GELCOM⁽⁹⁾. Forms for capturing and transmitting information between the GPM and the forecasting system will need to be designed to ensure the proper and systematic acquisition of the necessary data as well as the concise reporting of results to the GPM. Reports to the GPM will emphasize the accuracy of the input data, network structure models, and the activity duration and manpower estimates used in the network representations. As more sites are developed, which is occurring at an increasing rate, more historical data on the various network activities will become available. This information will be compared with the existing network models to verify their structures and also to determine whether additional network types are needed. The data will also be used to verify the activity duration and organizational manpower estimates as they are applied to the various networks, and to determine whether additional activity modules need to be incorporated. These reports to the GPM, as well as direct inquiries to the field, and the feedback they are likely to generate, will provide an added check on the validity of the information contained in the data base and on various assumptions involved in producing schedules and analyses.

6.5 System Software

The forecasting system software package should at a minimum accommodate the following features and capabilities:

- Site-specific status data are stored permanently.

- Generic schedules are stored permanently in the form of activity labels hammocked between major milestones.
- Resource requirements (e.g., manpower in a specific government office) are stored permanently.
- Site-specific schedules are generated by individual computer runs, and can be printed out, but will not be stored permanently.
- Intervals derived from site-specific history (site status data) will, for that site, override the equivalent estimate in the generic schedule for that site.
- The system will not automatically update activity time estimates from those that could be inferred from reported site status data.
- Major milestones will be assumed to be achieved if either (1) they are detected directly, or (2) all of the activities within the hammock have been detected directly, with the former receiving logical precedence.
- The system will permit the insertion of wild-card "show-stopper" milestones when these appear to affect development at certain types of sites. For example, "full scale binary technology not demonstrated" should stop development at all binary sites.
- The system will schedule and size the first site at each prospect based on (1) an announced plan by a utility, (2) a "first economic year" estimated from MITRE's GELCOM model, or (3) other estimates supplied by DGE. Precedence of these estimates should be negotiated on a site-specific basis.
- Scheduling and sizing of other than the first site at each prospect should be sensitive to manipulable parametric estimates of intersite intervals, reservoir power carrying capacity, and other known limitations on carrying capacity.
- The system, during production runs, should be capable of reporting (1) power on line estimates for years in a range to be selectable, (2) manpower requirements, by named governmental office of general manpower type, and (3) general capital and revenue requirements. The levels of aggregation, such as by states, prospects, etc. should be a user-selectable feature.

Although scheduling and its associated outcomes are a major aspect of this system, it has been determined that the classical PERT/CPM approach is not applicable to a problem of this broad scope. However, these techniques are appropriate for analyzing pieces of the problem. For example, CPM can be used to obtain aggregated activity values to be represented in hammocks and, likewise, aggregated hammock values to be represented in networks. The application of CPM would be particularly helpful when changing one or two activities in a complex hammock structure and estimating the effects of these modifications at the hammock or network level.

In consideration of these desired features and capabilities, it is apparent that the system software must be suitable for data base management and analytic operations. The principal functions of the data base management aspect concern maintaining data quality while those of the data analysis aspect can be categorized as scheduling, analyzing and tabulating, and reporting. Using a modular design concept, principal system functions and their components can be produced individually and combined gradually into the integrated software package which will be operated through an executive module. A block diagram of this design concept is given in Figure 6-3.

6.6 Operational Considerations

One particularly important aspect of the forecasting system is the methods to be used in handling developments at known and inferred resources. With regard to known resources:

FIGURE 6-3
PRINCIPAL SOFTWARE MODULES

- Sites will be based on the prospects listed as "identified" in USGS Circular 790 (Tables 4 and 5, pages 44-57)⁽¹⁾. Additional sites will be added as identified by other DOE contractors and approved for inclusion by DGE. The sites listed in the New Mexico Energy Institute's study of potential electric sites in the Rocky Mountain Basin and Range area are an example of candidate sites to be included.
- Sites will be included up to the estimated carrying capacity of each prospect, or as constrained by other known capacity-limiting constraints.
- The announced plans of industry for timing at each prospect will be included in each site-specific development schedule, or prospect-specific development scenario.
- When industry plans are not known, the system should be able to project schedules and scenarios based on documented estimates of when power at a site could economically compete with alternative electricity sources.

Sites related to inferred resources will be drawn from the USGS estimates of inferred resources in various regions of the United States:

- Where the inferred estimate of carrying capacity is small, each designated region will be treated as a single prospect.
- Where the inferred estimate of carrying capacity is large, say greater than 500 MWe for 30 years, the region will be broken into smaller areas, labeled "inferred prospects", using an assumed size-of-prospect distribution similar to that of the currently identified sites.
- As new prospects are added to the "known resources" category an equivalent amount of inferred resource of similar size will be withdrawn from the list of inferred resources.
- An "estimated date of discovery" will be appended to each inferred prospect, based on assumptions to be developed by MITRE and concurred with by DGE.
- Prospect development schedules will be based on the estimated date of discovery, and the same interplant lead time assumptions used for the known resources.

While planning schedules and scenarios for sites and prospects are fairly well understood⁽¹⁰⁾ the relationships in the probable timing between successive sites within a single prospect still have much uncertainty associated with them. There are at least four identifiable uncertainties that require further study:

- Operation of the first full scale site (say 50 MWe) proves the technical and economic feasibility of developing a resource. Other sites will not be started until the industry is convinced that the first one is doing well. "Doing well" is intangible. Industrial representatives should be interviewed to determine reasonable assumptions in this matter.
- After a number of sites have been installed, the carrying capacity of the prospect reservoir will be reached. This will be signalled, many years from now, by pressure drops in the reservoir. The degree of caution of the developers in adding the last sites at each prospect will be variable and difficult to anticipate. This should be explored further, through stochastic analysis of the economic risks associated with under- and over-development of prospects.
- The "normal" inter-site lead time can be expected to vary from place to place. However, for the first approximation, the experience at The Geysers should be followed.
- The effects of non-resource constraints also need to be considered in estimating the ultimate carrying capacity of specific prospects. These include the lack of sufficient cooling water and the potential that the cumulative annual air or water emissions from a group of sites will exceed some statutory/regulatory limit. These constraints should be dealt with as they are detected, and as reasonable data for dealing with them become available.

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