Expert Systems for Integrated Development: A Case Study of Shanxi Province, The People's Republic of China

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FOREWORD

The research and development project described in this status report is a collaborative project between IIASA and the State Science and Technology Commission of the People's Republic of China (SSTCC).

The project objective is to build a computer-based information and decision support system, using expert systems technology, for regional development planning in Shanxi, a coal-rich province in northwestern China. Building on IIASA's experience in applied systems analysis, the project develops and implements a new generation of computer-based tools, integrating classical approaches of operations research and applied systems analysis with new developments in computer technology and artificial intelligence (AI) into an integrated hybrid system, designed for direct practical application.

To provide the required information, several databases, simulation and optimization models, and decision support tools have been integrated. This information is presented in a form directly useful to planners and decision makers. The system is therefore structured along concepts of expert systems technology, includes several AI components, and features an easy-to-use color graphics user interface.

The study is being carried out with intensive collaboration between IIASA, and Chinese academic, industrial, and governmental institutions, especially the regional government of Shanxi Province.

The report describes the status of the project after one year of research, summarizing the problem area, the design principles of the software developments and the current status of prototype implementations.

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The collaborative study draws on contributions from the Institute for Control & Systems Engineering (ICSE), Academy of Mining and Metallurgy, Cracow, Poland; the Institute of Chemical Technology of the Academy of Sciences of the GDR; the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES), College of Engineering and Applied Science, University of Colorado at Boulder, USA and the Section of Economic Studies, Division of Nuclear Power, International Atomic Energy Agency, Vienna, Austria.

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DISCLAIMER

The opinions expressed in this report are those of the authors and do not necessarily reflect those of IIASA or of SSTCC. Neither the SSTCC or IIASA, nor any person acting on behalf of the above is responsible for the use which might be made of the information in this report.

The basic user requirements and the minimum structural core of the system was defined in a Memorandum of Understanding between IIASA and the SSTCC dated 14 December 1985.

Any additional software components and features of the system described in this report do not constitute an implicit commitment on the part of IIASA for delivery in excess of the system's specifications set out in the Memorandum of Understanding.

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EXPERT SYSTEMS FOR INTEGRATED DEVELOPMENT: A CASE STUDY OF SHANXI PROVINCE, THE PEOPLE'S REPUBLIC OF CHINA

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1. Project Summary Description

The coordinated development of a region, and its industrial structure in particular, requires the simultaneous consideration of numerous inter-relationships and impacts, e.g., resource requirements, environmental pollution, and socio-economic effects. Plans and policies for a rational and coordinated development need a large amount of background information from various domains such as economics, industrial and transportation engineering, and environmental sciences, in a readily available format, directly usable by the planner and decision maker. However, the vast amount of complex and largely technical information and the confounding multitude of possible consequences and actions taken on the one hand, and the complexity of the available scientific methodology for dealing with these problems on the other hand, pose major obstacles to the effective use of technical information and scientific methodology by decision makers.

The aim of the project is to develop an integrated system of software tools to make the scientific basis for planning and management directly available to planners, policy and decision makers. Concepts of *artificial intelligence* (AI) coupled with more traditional methods of *applied systems analysis* and *operations research* are used. These tools are designed to provide easy and direct access to scientific evidence, and allow the efficient use of formal methods of analysis and information management by *non-technical* users as well.

Within the context of a selected *regional case study* (Shanxi Province, The People's Republic of China), the project is developing an operational *prototype level expert system* (model-based interactive information and decision support system with an intelligent, graphics-oriented user interface, and integrated AI technology and components) that will be used by the regional government of Shanxi Province for development planning.

The overall problem situation addressed by the case study could be described as follows: how to plan for integrated industrial development centered on a primary resource, namely coal, maximizing revenues from industrial production for a set of interdependent activities, subject to resource constraints and minimizing external (i.e., environmental) costs.

In the specific regional case study of Shanxi province, development involves the introduction or intensification of the following major

Activities:

- Coal mining and processing: The coal deposits in Shanxi in total cover 57,720 km^2 with an estimated reserve of 900 billion tons and proven reserves of 205 billion tons; the 1984 raw output was 187 million tons, and in 1985 reached 210 million tons;

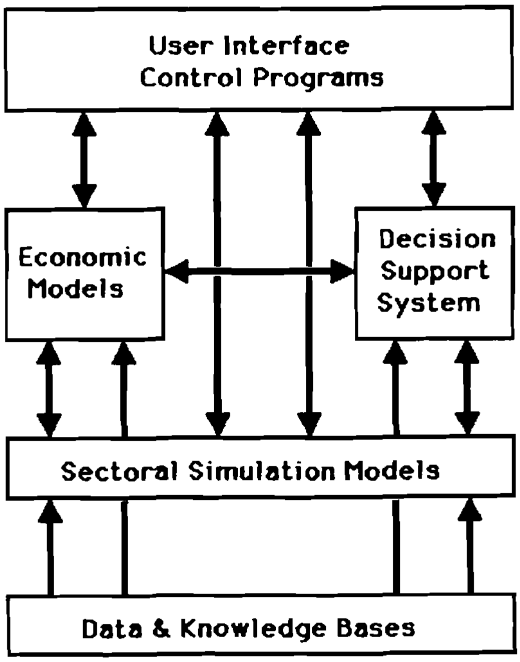

Figure 1: Structure and integration of the system's components

- Metal mining: mineral resources include iron, copper, aluminium, molybdenum, titanium, lead, gold and silver;
- Chemical industries (coking, coal gasification, liquefaction, coal-based fuels and feedstocks, intermediates etc.): important chemical products also include inorganic salts (sodium sulfide and sulfate), fertilizer, agricultural chemicals, rubber;
- Power generation (coal-fired) and distribution: concentrated around coal fields, large power stations generate more than 2.4 gigawatt at the Datong Second Power Plant, connected via the Datong–Beijing 500,000 volt high-tension power line; Shantou and Zhangze Power stations contribute another 3 GW to the system;
- Iron, steel, aluminium, and copper production: The main producers are The Shanxi Aluminium Works with a design capacity of 400,000 tons of aluminium, and the Taiyuan Iron and Steel Complex with a broad production palette of 450 kinds of steel;
- Industrial manufacturing: ranging from machinery (mining equipment, locomotives, hydraulic and electrical equipment, bearings) to light industries, e.g., textiles;
- Transportation (largely coal): only partly electrified, the railway system in 1983 handled a freight volume of 138 million tons, including 118 million tons of coal; the road system currently includes a total of 28,700 km "open-to-traffic" (including about 23,000 km "all-weather" roads);

- Agriculture: with wheat, corn, and Chinese sorghum being the dominating crops; forestry with about 16,000 km^2, more than one third the result of recent afforestation, is gaining in importance;

The major *Activities* are subject to a number of

Constraints:

- Capital: 1984 level of investment was about 40 billion yuan, and the projected yearly growth rate for the Province to the turn of the century is 7.5%;
- Water resources: total volume of the province's yearly water resource (precipitation minus evapotranspiration) is 142 billion m^3, out of which about 64 billion m^3 have been developed; the problem, however, is also one of location and distribution;
- Transportation network: the transportation network of railways and highways covers a total of 36,000 km and is used intensively for the transportation of freight. However the network is not sufficient to cope with the volume of freight. The low standard of construction and resultant bottlenecks in traffic movement impedes the flow of commodities.
- Environmental degradation: air and water pollution, soil erosion;
- Industrial labor force (3.5 million, out of a total population of 26 million); an important problem, however, is the shortage of skilled labor;
- Export targets (coal): by the end of the century, the Province plans to market (within China) 270 million tons in addition to 30 TWh of electrical energy;

The achievement of a balanced and sustainable development despite some of the above constraints (e.g., environmental pollution) could alternatively be formulated as *Policy Objectives* (e.g., maximization of revenues from regional industry, minimization of environmental pollution).

To design and evaluate alternative development policies in terms of the above activities, objectives, and constraints, the primary

Information Requirements for Decision Support include:

- Background information on the *status quo* and likely development options, including inter-regional comparisons that can assist in formulating development objectives;
- Design and analysis of feasible development policies (optimization of individual activities, designing/optimizing sets of coordinated activities), including:
    - Economic analysis (input/output, cost/benefit, for the regional economy and industrial activities or technology alternatives, respectively);
    - Resource requirements and allocation (e.g., water, capital);
    - Environmental impact analysis;
    - Comparative evaluation of composite development alternatives (policy analysis).

To provide the required information, we integrate several databases, simulation and optimization models, and decision support tools. This information must be presented in a form directly useful to planners and decision makers. The system is therefore structured along concepts of expert systems technology, includes several AI components, and features an easy-to-use color graphics user interface.

1.1 The Expert Systems Approach

There is no generally accepted definition of what constitutes an expert system. There is, however, general agreement that an expert system has to combine

- a knowledge base, that is a collection of domain-specific information;
- an inference machine, which implements strategies to utilize this information and derive new conclusions (e.g., modus ponens, forward chaining, backward chaining);
- and an explanation component, or in more general terms, a conversational interface that elicits input required from the user and, on request, explains the system's inference procedure.

Obviously, an expert system must perform at a level comparable to that of a human expert in a non-trivial problem domain.

While most operational examples of expert systems work in a very small and well-defined problem domain (computer systems configurations, interpretation of chromatographic experiments, diagnosis of a small set of illnesses, etc.; for a recent review see Weigkricht and Winkelbauer, 1987) our system spans a very large and not-so-well defined problem area.

The model for our expert system's design is therefore based on the concept of

- a **team of experts**, coordinated by
- a **systems analyst**, who orchestrates the tasks of the
- individual **domain experts**.

Primary interaction is through the systems analyst, represented by the menu-driven and largely symbolic user interface. The user interface translates the user's request and specifications into tasks the system can perform, calls upon the domain experts (models and databases), and communicates their results to the user.

The expert systems approach has three major components:

- a conceptual or representation component,
- a technological or implementation component, and
- a procedural or development component.

The conceptual component is largely concerned with the user's perception of the system: the computer, through its software, must appear "*intelligent*", interaction with the system must be natural, easy, and conversational, including all the subtle corrective feedback mechanisms used in human conversation. These concepts are implemented through the system's framework and structure, problem representation (drawing on declarative as well as procedural concepts) and the user interface design with its emphasis on symbols and graphics.

The technological component includes all the techniques used to achieve these goals, i.e., the use of declarative languages and concepts in addition to the classical procedural ones, and the appropriate elements from the toolkit of AI research (see sections 2.1 and 3).

Finally, there is a procedural or development component: the basic method behind the study is *knowledge engineering* and *rapid prototyping* together with and around well-established operations research techniques. The study attempts to draw directly on the expertise of several collaborators, facilitating the structuring and integration of their input by using a series of prototype versions of the system's modules which is used as a guide for the knowledge engineering and acquisition process.

Rapid prototyping can be understood as an experimental, adaptive, and highly interactive approach to software engineering. It is ideal for systems development whenever detailed and rigid user requirements cannot be laid down *a priori*, but are likely to evolve together with the system. Good applications for rapid prototyping are those that tend to be dynamic and interaction-oriented, with extensive use of user dialog (Klingler, 1986).

The prototypes of the system's modules provide a specific problem representation "language". They allow a domain expert, who is rarely a computer specialist, to interact with the system with the help of a knowledge engineer, and to understand better how his expertise gets represented.

The prototyping approach is incremental and iterative in nature. In our design, the numerous modules are initially developed independently, in small units that are easy to manipulate. The modular and open architecture of the overall system makes their integration easy (see section 4.1). The frequent replacement of modules with increasingly improved versions is supported through standardized interface components. This relative independence of modules is also important to ease the task of keeping the system current, adapting to the experience gained by its use, and extending its functionality in the future.

The overall system is designed as a ***hybrid system*** (see section 3.2), combining classical data processing methodology and the methods of operations research and systems analysis with concepts and techniques of AI. Conceptually, the main functional elements of the integrated software system are (Figure 2):

- an **Intelligent User Interface**, which provides access to the system's workings to the user. This interface must be attractive, easy to understand and use, and to a certain extent provide the translation between natural language and human style of thinking to the machine level and back. This interface must also provide a largely menu-driven conversational guide to the system's usage (dialog - menu system), and a number of display and report generation styles, including color graphics and linguistic interpretation of numerical data (symbolic/graphical display system);
- an **Information System**, which includes the system's Knowledge and Databases as well as the Inference and Database Management Systems, which not only summarizes application- and implementation-specific information, but also contains the most important and useful domain-specific knowledge;
- the **Model System**, which consists of a set of models (simulation, optimization), which describe individual processes that are elements of a problem situation, perform risk and sensitivity analyses on the relationship between control and management options and criteria for evaluation, or optimize plans and policies in terms of their control variables given information about the user's goals and preferences according to some specified model of the system's workings and rules for evaluation;
- the **Decision Support System**, which assists in the interpretation and multiobjective evaluation of modeling results, and provides tools for the selection of optimal alternatives with interactively defined preferences and aspirations.

Approaches, methods, and tools of AI and expert systems technology are embedded in the overall system at various levels and at various points:

- the object-oriented overall design and problem representation structures the integrated system along the concepts of expert systems (compare section 3 and 4.1);
- the user interface includes various elements of expert systems technology, e.g., natural language parsing, rule-based input checking and error correction;
- throughout the system, context-dependent help and explain functions are foreseen;
- selected model components are based on AI software engineering techniques, including a frame-based, object-oriented and message-passing symbolic simulator for overall regional development, implemented in CommonLisp and Flavors (see 2.1 and 3).

Another example currently under development is the implementation of Prolog-based tools for relational analysis for the siting of industrial enterprises (technologies) in Shanxi (section 2.2.3); the approach foresees the matching of technology-specific production requirements with policy- and location-specific production environments, both

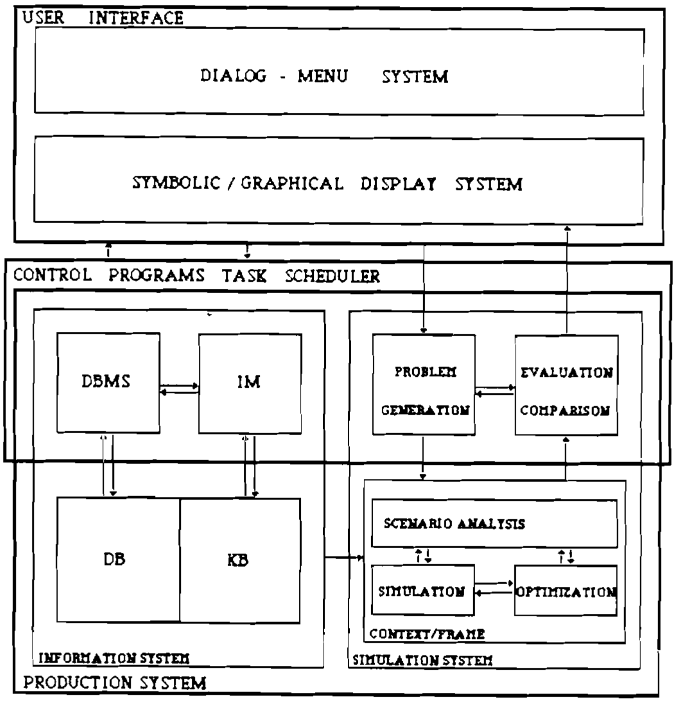

Figure 2: Elements of the integrated software system

represented in predicate logic, and supported with an interactive knowledge base editing facility for requirements, environments, and policy options.

Clearly, meaningful representation of a system as complex as a large region with its compound development problems exceeds the scope of traditional mathematical or statistical approaches. Precedent, or simply human expertise and judgement have to be used where statistically derived evidence and hard observational data are missing by necessity, because the regional economic development planning field is obviously variable-rich but sample-poor. Many relationships, in particular from the technological and physical components of a regional system, may be well known. However the consequences of yet untested policies, of behavioral response to entirely new economic situations, of changes in lifestyle and the very fabric of a rapidly changing society can at best only be speculation. Intuition and experience will have to replace experiment and direct observation. The number of potentially relevant variables is very large, and repeated systematic experimentation is virtually impossible. Innovative use of analogies, pattern matching and common sense must fill this gap. Common sense rules, for example, define the constraints that resource availability imposes on development options, or how political and cultural conditions shape development strategies. Integrating these representations of common sense, intuition and experience, with the traditional approaches of numerical analysis into one coherent framework is a major objective of our expert systems development.

1.2 A Description of Shanxi Province

Geographic features:

Shanxi is situated in the middle of central north China. It is a part of the northwest loess plateau in the country. The total area of the province is about 156,000 square kilometers, and the population is 26 million (1982 estimate). Most of the province lies 1000 meters above sea level and both the eastern and western parts are mountainous or hilly (up to 80% of the total area). There are five fault subsidence basins crossing the whole province from north to south.

Current land utilization is as shown in Table 1:

Table 1: Land use in Shanxi Province

Arable land	39,000	km^2	25%
Forested	15,600	km^2	10%
Grassland and pastures	35,900	km^2	23%
Undeveloped	46,800	km^2	30%
Wasteland	18,700	km^2	12%

Climate:

The climate is moderate-continental. The average annual temperature is 4° to 14° C. The annual precipitation is 534 mm on average. The frost-free period averages 150 days per year. The climatic conditions of most of the region are suitable for agriculture.

Mineral resources:

Shanxi is rich in mineral resources. There are over 80 varieties of verified mineral resources including coal, aluminium, iron, copper, gypsum, mirabilite, refractory clay, limestone, etc. The most outstanding resource is coal, which spreads over an area of approximately 58,000 square kilometers (37% of the overall area of the province). The estimated reserves are 860 billion tons and the proven reserves 200 billion tons. Shanxi is not only rich in coal reserves, but has coal of a superior quality (with a heating value of 7000-8000 kcal), and in diverse varieties (coking coal, anthracite, high-grade coal for power generation, etc.) The seams are stable, concentrated and close to the surface of the earth, therefore easy to extract (the cost of mining is only two-thirds of the national average). The verified bauxite reserves also rank first in China. They too occur in stable, concentrated seams, with high-aluminium, high-silicon and low-iron content.

Water resources:

The Yellow River flows along the western border of the province. There are five rivers, namely the Fen, Qin, Shushui, Xinshui and Sanchuan which are part of the Yellow River system, and three rivers, the Zhang, Huto and Sanggan, belonging to the Hai River system (which is the main river in the neighboring province Hobei). On account of the large proportion of limestone and the porous soil, the loss from drainage is a critical problem. The land formation induces groundwater and surface water systems to flow towards the east, south and west. Water resources mainly depend upon precipitation, which on average is 534 mm, or equivalent to 83.5 billion cubic meters of water. However, the dryness of the region brings the annual evaporation up to 416 mm, which is equivalent to 69.3 billion cubic meters. As a result the available water is only about 14.2 billion cubic meters. Shanxi therefore suffers water shortages which affect both industrial and domestic demand.

Agriculture:

The arable land area is 58 million mu (equivalent to 3.85 million hectares), of which 30 million mu are in hilly regions and 28 million in basins. The agricultural activities concentrate more on labor-intensive crops, which are about 59% of the total agricultural output value; 5.5% is generated by forestry, 9.5% from livestock and 26% from sideline products and rural industries. Among the crops, 80% is grain, 14% industrial crops and 6% others. Annual production of grain is 8 million tons or 308 kilograms per capita. The proportion of grain imported from other provinces is about 14% while the output (mainly corn) is about 5%. The forested land area is approximately 4 million mu (260 thousand hectares). The percentage of meat in livestock products is 70%. The total production of livestock products is 300,000 tons per annum of which 80,000 tons are milk products.

Industry:

The outstanding feature of industry in Shanxi is the large proportion of heavy, primary and labor-intensive industries. The percentage of the mining industry in the total industrial output value is 26%; of the raw material industry 21%; and of the manufacturing industry only 22%. The main industries are as follows:

(1) *The energy industry* is the core sector of the economy in Shanxi. The output value of the energy industry amounts to 32% of the total industrial output value. In 1985, the output of raw coal was 210 million tons, which constitutes about one-fifths of the annual production of the whole country. Coal from Shanxi is exported to 26 provinces and has significant influence on the development of the economy in these provinces. The growth of the electric power industry is rather slow. It constitutes 5% of the power industry of the whole nation. In some districts of Shanxi the shortage of electrical energy is a critical problem.

(2) *The metallurgical industry*. There are three main iron and steel complexes. The annual output of iron is about 2 million tons, of steel about 1.6 million tons and of steel products 1 million tons. The infrastructure of the metallurgical industry shows some irrationalities. The lopsided development of the production structure was inclined toward iron and steel. The ratio of output of the iron and steel industry to the non-ferrous industry is almost 100:1. Among the non-ferrous metals industries, aluminium has priority for development. As for the iron and steel industry itself, the capacity of ore dressing and agglomeration plants does not match that of iron smelting; the capacity of steel mills does not match that of steel smelting due to equipment shortages.

(3) *The chemical industry*. In this sector there are 1000 enterprises of different sizes with 150,000 workers in all. The main products are: sulfuric acid, fertilizer, soda, pesticides etc. Downstream products are rare. The capacity of the chemical industry in Shanxi amounts to about 4% of the country's capacity but output value amounts only to 2.03%.

(4) *Manufacturing industry*. There are about 3000 enterprises of different sizes in this sector. The main products are: mining machinery, pumps, ventilators and compressors, electric appliances, farm machinery etc. In keeping with the proportion in output value, farm machinery represents 5%, production machinery 26%, metal working 16%, consumer goods 5%, electronic industry 3%, etc. The output value of the electronic industry is only 1% of the national total. There is a dearth of precision products.

(5) *Light industry*. The light industries in Shanxi mainly use farm products as raw material (68%). There are only a few factories taking industrial products as raw material (32%). The textile industry has rudimentary products only. The end products of the food industry are: sugar, canned food, wine etc. The main issues to be dealt with in the development of light industry are the shortage of raw material and the low quality of products.

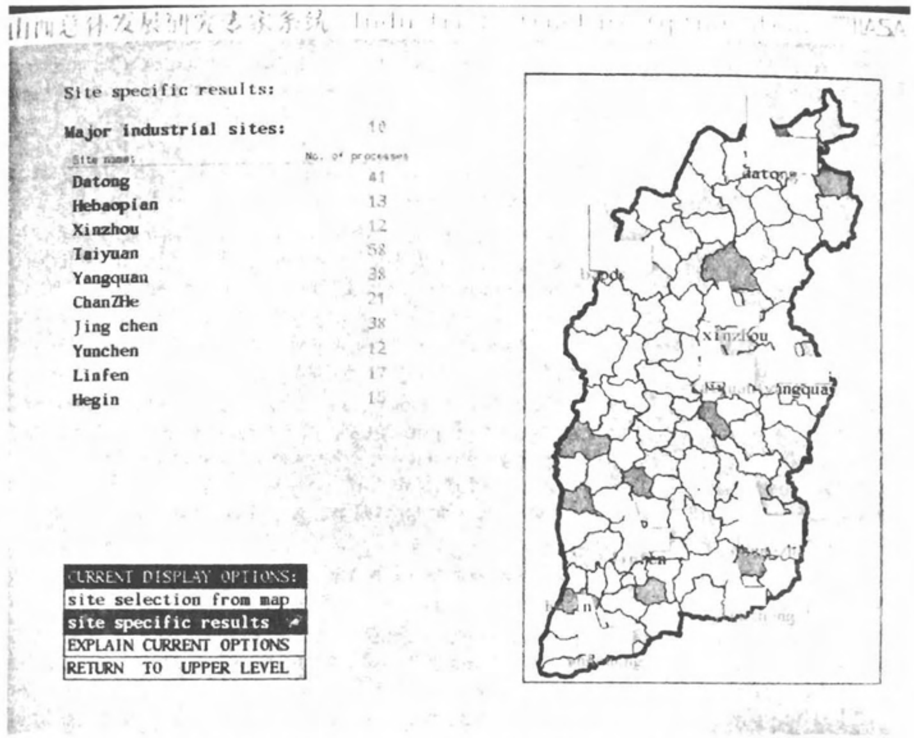

Figure 3: Major industrial sites (output from the PDAS model)

Transportation and Communication:

A transportation network of trunk railways and highways has already been established in Shanxi with a total length of 30,870 kilometers. There are seven trunk railway lines and twelve branch lines, with a total length of 2,170 km. The roadways are now 28,700 km, with trunk lines totaling to 9,300 km. The amount of freight transported is very high; up to 200 million tons per annum, 60% by railway and 40% by highway. 90% of railway freight volume is for coal transportation. The ratio of export to import of freight is 8.5:1, which is an outstanding feature of transportation in Shanxi. The issues to be dealt with in highway transportation are: limited trackage and roads, low construction standards, lower capacity for traffic flow which, to some degree, impedes commodity flow.

The development of post and telecommunication still cannot meet the requirements of economic growth. The provincial long-distance call lines totaled 32,000 km and local telephone lines 6,600 km. An efficient, high-level telecommunication network should be planned.

1.3 Development Problems and Development Objectives

The Shanxi province authorities have mapped out a development program to make full use of its favorable conditions and to contribute to the modernization of China. There are several problems connected with economic development that have yet to be solved. The major problems are:

(1) Shanxi's economy has a low efficiency. In industry, compared with the national average, the output value and revenue are about 36% below the average level; the profits and taxes are 30% below; and the overall labor productivity is 29% below. This is due to the irrational infrastructure and spatial distribution, less developed technology and management practices currently in use. A consequence is the lower income and living standard of the inhabitants. It is vital to now pursue development alternatives suited to Shanxi which would lead to steady growth, better economic results and more substantial benefits to the people of Shanxi.

(2) The lopsided pursuit of increased output and output values of industry, especially heavy industry (mainly coal mining to meet the ever increasing demand) led to serious imbalances with regard to agriculture, light industry and heavy industry. In the industrial sector, it is inclined to primary, labor-intensive sectors with low profits and adaptability. High-technology enterprises are rare. Adjustments to the infrastructure of industry, and of the economy as a whole, are a critical problem.

(3) There are three main constraints to the development of Shanxi's economy: transportation, water resources and qualified personnel. Transportation is currently the main bottleneck. The transportation network consists only of railways and highways with limited load capacity and out-of-date facilities. It cannot cope with the volume of coal exported. There are also problems in linking-up different kinds of transportation lines.

As mentioned earlier, water resources are scarce and will be more crucial in the near future.

There is a severe shortage of competent technical and managerial personnel in Shanxi. The number and quality of Shanxi's blue- and white-collar workers are far below the national average. There are fewer than 100 university students per 10,000 labor force. There are a lot of sectors where lack of technical personnel hampers technical progress.

(4) Technology and management are Shanxi's weak points. There is not enough technical expertise to transform traditional industries by the introduction of new technologies. The economic growth of the province depends upon new construction projects rather than equipment renewal and technological transformation. In aspects of management, planned development of the commodity economy is just at the beginning stage. The elimination of the old structure and the building of the new can only be gradual and will take time to complete. Old and new structures will continue to coexist and interact. It will be more difficult to exercise effective macro-control and to make rational use of micro-mechanisms. The relations between public-owned, collective and private enterprises, between the state, the producing unit and producers as individuals must be appropriately adjusted.

The development objectives of Shanxi are:

(1) By the year 2000, the annual industrial and agricultural output value should be quadrupled from the 1980 basis. It means that in the next fifteen years, an annual average increase of 7.5% must be ensured.

(2) An appropriate rate for raising the living standard by taking into account the needs of both production and consumption will be set. By 2000, the annual per-capita gross output value will be 800-1000 U.S. dollars.

(3) The simultaneous development of the economy, society, science and technology, and ecological balance will be taken into consideration. A favorable economic, social and ecological environment will be created, which is the basic guarantee and prerequisite for further development in the twenty-first century.

1.4 Economic Management and Planning in Shanxi

The management system in Shanxi consists of the administrative system of planning, production, construction, finance, science and technology (Figure 4). Each of the systems is under the leadership both of the corresponding ministry in the central government and the provincial government.

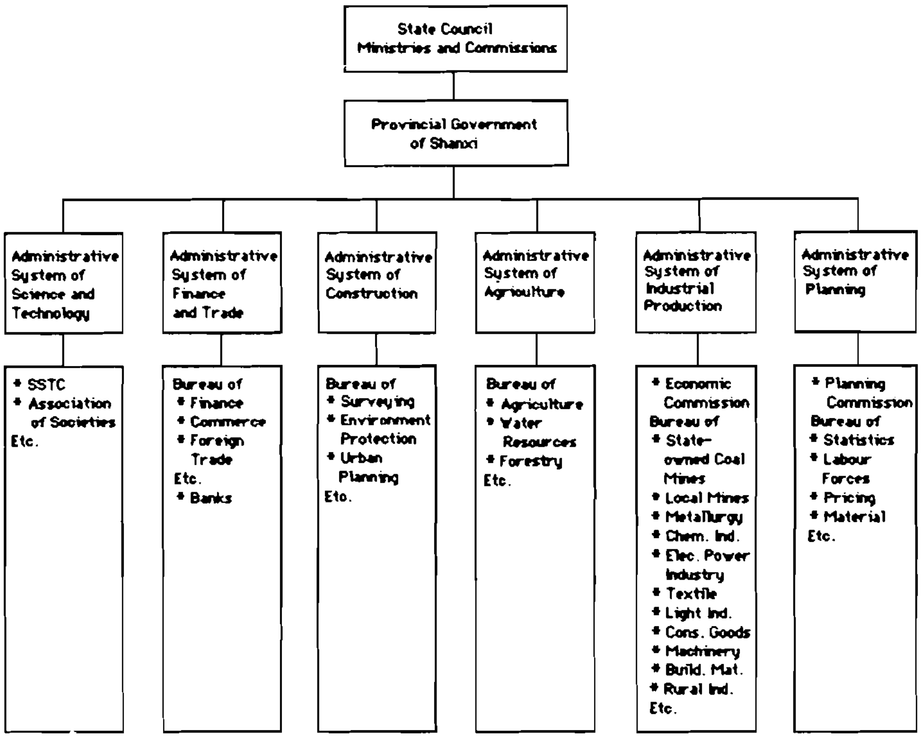

Figure 4: The management system in Shanxi

There are three types of ownership: public (state ownership and province ownership), collective ownership and private ownership. A typical example is that in the year 1985, 40% of coal output was from state-owned mines, 20% from mines owned by the provincial government and 40% from collective and private mines. The rapid growth of collective and private enterprises in recent years is due to the policy shift.

For a long time, Chinese economic management systems concentrated on centralized administration. Production and management of the enterprises (most of them publicly owned) were controlled directly by administrative units at various levels. The government provided the enterprises with the means of production and handled all distribution. Financial affairs were also managed by the government. Market function was negated. The initiative of managers and workers was severely restricted. An unusual situation had occurred: on the one hand, the supply of certain products fell short of demand, while other products were in surplus.

In recent years, China has begun to adopt management methods such as mandatory planning, guidance planning and/or market regulation with regard to different enterprises, products and tasks. In Shanxi, for example, the state-owned and province-owned mines turn out products under the direct mandatory planning of the state (for province-owned, also of the province). The rapidly growing collective and private mines, which

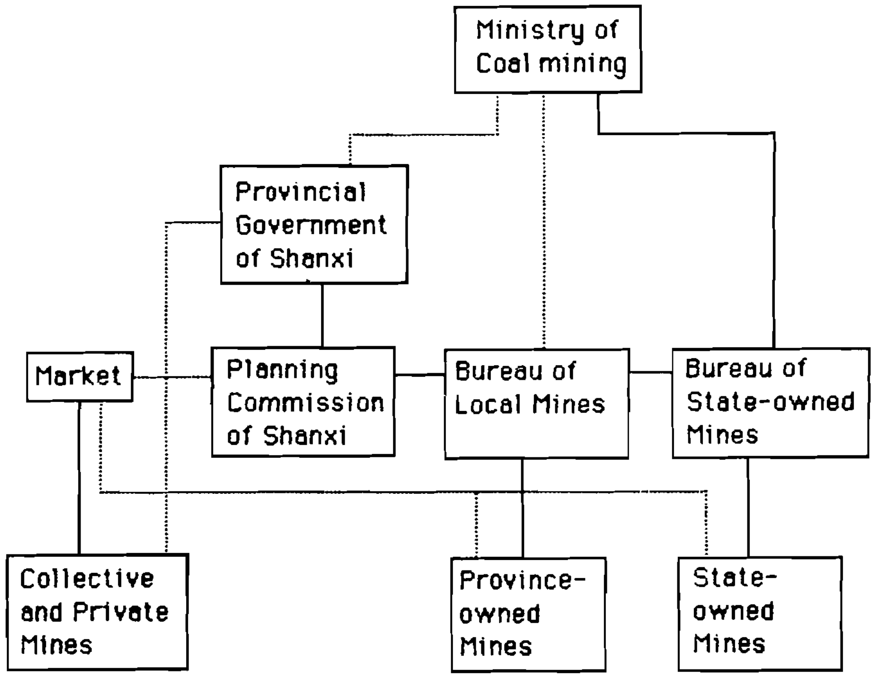

Figure 5: An example of the planning and market mechanism

are scattered all over the province, operate according to market conditions and under the guidance of state and local planning (Figure 5). Of course, somewhere between these two categories, there are some mines turning out products mostly according to state plans, but partially according to market conditions, or just the reverse. Now the varieties and quantities of products under unified state allocation and distribution have been appropriately reduced. The role of market regulation has been strengthened. The decision-making powers of enterprises have been broadened. State planning is the basis for providing macro-economic guidance to ensure the proper development of the economy. A new economic management system is just taking shape, which organically combines planning with marketing, micro-flexibility with macro-economic control, and centralization with decentralization. Central and provincial governments should pay more attention to long-term strategic planning.

1.5 The Role of the Proposed System

Since the state and the province changed their economic management policies, mainly with the objective of better overall planning, implementation of policies, organization, co-ordination and use of economic means of regulation, there are quite a lot of decision-making problems for the leaders of Shanxi province. In order to place the decision-making process on a scientific basis, computer-based decision support systems (DSS) have been recognized as necessary tools. This type of computer system is - unlike management information systems (MIS) - not specially built for routine tasks, but specifically for decision support for long-range strategic planning.

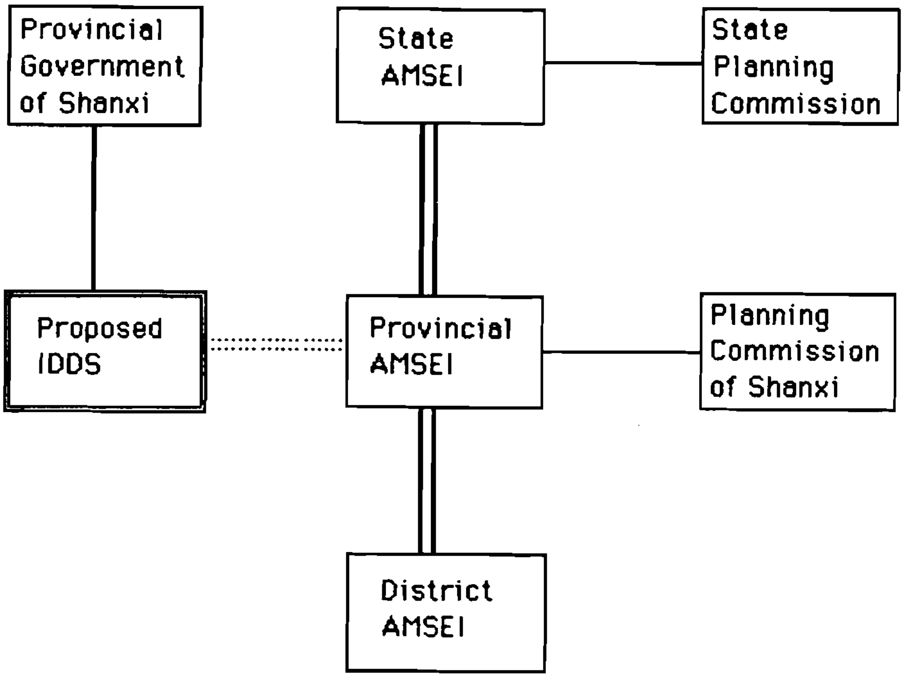

Figure 6: The relation between AMSEI and the proposed DSS

In keeping with the program of the State Planning Commission, a unified automated mangement system of economic information (AMSEI) is now under construction. This system has a hierarchical structure and there is a subsystem under the supervision of the Planning Commission of Shanxi (Figure 6). It has the task of daily processing economic information on the province. The goal of this system is the rationalization of the information flow and full utilization of the information. In this system, there are also planning tasks, but only at the administrative level.

The proposed DSS is being developed as a direct aid to top-level decision makers so as to enable them to deal with unpredictable and ill-structured problems with greater ease. It accentuates problem-mindedness (Dery and Mock, 1985) over solution-mindedness, in that it perceives as critical the need to explore the nature of the problem and to generate alternatives rather than purely to dwell on the choice among alternatives, as this last precludes, or at least inhibits, the exploration of novel avenues.

The decision makers and their staff usually spend a good deal of time collecting and processing the required (mostly aggregated) information before making their decisions. The proposed system will relieve this workload. The user may extract information from the databases of the system and form some judgement directly from data or by a comparative study.

The proposed system will develop some scenarios of complex problem situations, taking into consideration the intuitive judgement of decision makers. Scenarios provide decision makers with the opportunity to introduce their own knowledge and assumptions. Economic activities will be simulated in the system and feasible development policies may be analyzed.

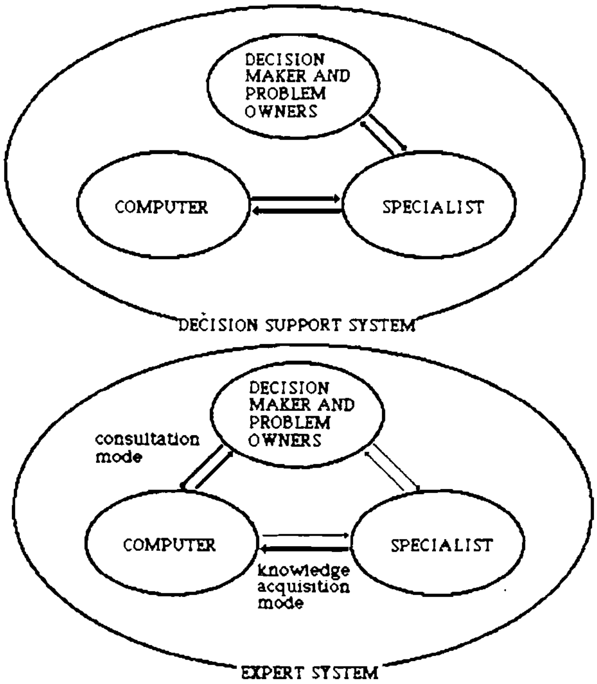

Figure 7: The role of decision makers, specialists and the computer: DSS versus the expert systems paradigm (from Fedra and Otway, 1986)

The proposed system will assist in the interpretation and multi-objective evaluation of the simulation results, and provide a tool for the selection of optimal alternatives with interactively defined preferences and goals.

Top-level decision makers are often not computer experts, therefore the proposed system should be user-friendly. They should be able to consult the system directly and not only through the specialist (Figure 7). In some cases the decisions are made hurriedly, in tense situations, so the system must have flexibility and adaptability.

As a next step, a communication link between the provincial AMSEI and the proposed system will have to be installed (as shown by the dotted lines in Figure 6) primarily for information retrieval, i.e., the workstation-based system will connect to the AMSEI for either direct, on-line retrieval of data for display and analysis within a given interactive session, or use the AMSEI as a source of data it can download to update its local databases in a special database management mode of operation.

2. Components of the Software System

The basic user requirements and the resulting functional components of the system have been specified and listed in a Memorandum of Understanding between IIASA and the SSTCC, defining a minimum structural core for the system.

During the first design phase, several additional modules were identified for possible inclusion into the system, and some of the original concepts had to be modified in view of the information becoming available from Shanxi Province. As a result, the description of the system's components below is to be understood as a description of the current status of our framework design, which will certainly be subjected to numerous revisions before the final system's implementation.

From an implementation point of view, the overall system can be conceptualized as three interdependent layers, comprising the macro-economic and strategic planning level, the sectoral and intersectoral level, and finally the level of the databases. For the user, all the three levels are hidden through a more problem-oriented interface structure (see section 3).

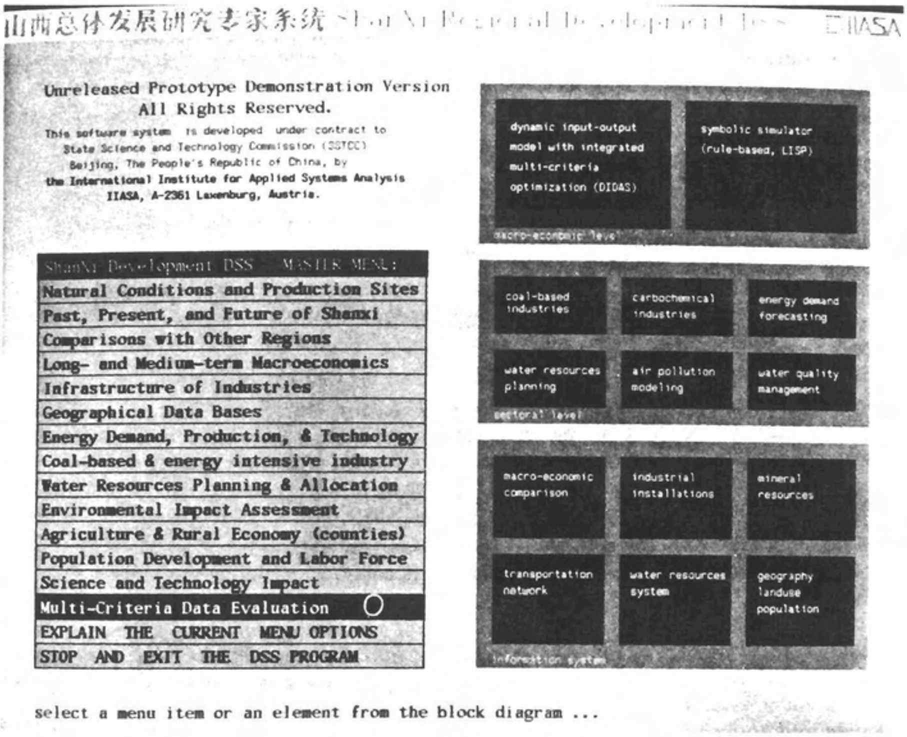

Figure 8: The system's components seen through the master menu

At the macro economic level, the system foresees the use of an economic development planning module, consisting of a dynamic, rule-based simulation model and, in parallel, a dynamic input-output model. They are linked to the sectoral simulation models (section 2.2); and can also be understood to summarize and aggregate their results.

The sectoral level is represented by optimization and simulation models, describing coal-based, carbochemical and energy intensive industries respectively. These classifications are, of course, not mutually exclusive but largely overlapping. In addition to these sectoral components, inter-sectoral models describe water resources and air pollution.

Finally, databases are being developed on the following:

- macro-economic summary (including inter-regional comparison data);

- industrial areas and production sites;
- industrial production technologies;
- transportation network;
- water resources and climate;
- geographic background, land use, and population.

2.1 The Macro-economic Level

At the top level of aggregation, the macro-economic models represent the entire province within one conceptual framework. The sectoral aggregation of the macro-economic modules is kept flexible for the user, offering several levels of aggregation (in particular for the Input-Output model, see section 2.1.1), ranging from 3 to 56 sectors.

The basic disaggregation comprises the following 22 sectors:

1) Agriculture
2) Forestry and silviculture
3) Coal mining
4) Mineral resources mining
5) Power generation and distribution
6) Metallurgical industry (iron and steel)
7) Metallurgical industry (nonferrous metals)
8) Coking and coal processing
9) Petroleum industry
10) Chemical industry
11) Manufacturing (mechanical engineering)
12) Electronics
13) Construction materials industry
14) Forest industry (timber processing)
15) Food production and processing
16) Textile industry
17) Other industries
18) Building and construction
19) Transportation (railway)
20) Transportation (highway)
21) Postal services and communication
22) Trade and commerce

While this level of aggregation will be used for several models, and in particular the interface between several modules of the system (e.g., with MAED, the Symbolic Simulator, PDA, etc.), other levels of aggregation and disaggregation are being used as well (compare section 2.1.1).

The macro-economic level will be represented by

- a dynamic, qualitative (symbolic) simulation of regional economic development, based on principles of system dynamics and rule-based symbolic simulation;

  This model will be complementary to an

- economic input-output model, with various levels of output aggregation, and linked to the parallel symbolic simulator and, in a hierarchical structure, to the sectoral models.

At least one dynamic input-output model with a disaggregation into 56 sectors, exists for the region (e.g., Xia and Zhao, 1986) This will be implemented within a multiobjective optimization framework, based on IIASA's DIDASS software (section 2.1.2).

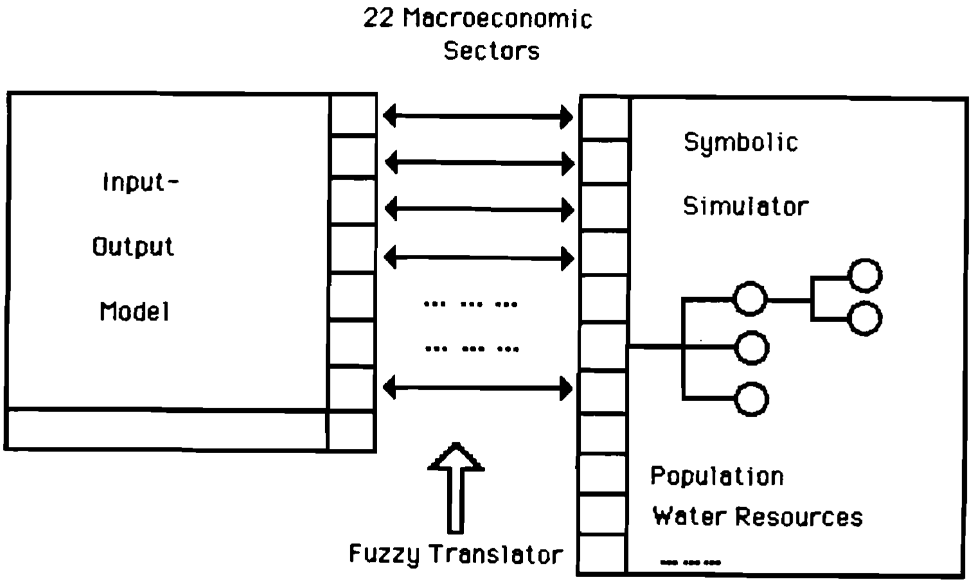

Figure 9: Coupling of the Input-Output model and the Symbolic Simulator

Major developments around the basic input-output model should include:

- coupling with sectoral simulation models that provide "independent" estimates for individual table values, rows, or columns;
- modification of coefficients and boundary conditions through a symbolic, language-oriented or graphical interface (section 2.1.3);
- interactive aggregation/disaggregation moving from smaller sets of combined sectors for easy display of connections to the full sectoral resolution;
- an appropriate graphical display of the I/O table, e.g., by scaling symbolic descriptors of the individual sectors and their interconnecting flows.

In parallel, i.e., using the same set of sectors (at the top level), a simple dynamic simulation model will be built. The model is based on concepts of system dynamics (e.g., Forrester, 1971), describing causal relationships in time. It will be implemented, however, as a symbolic rule-driven and object-oriented simulation model using a frame representation for macro-economic objects. The model dynamically links (through discrete time steps) problem-relevant variables such as investment, jobs, energy consumption, output, and revenues via auxiliary variables such as age of capital equipment or unit output per unit machine of a specific technology and appropriate interaction coefficients, all expressed in natural units through a system of causal relationships, i.e., feedback loops (positive and negative), subject to a set of constraints and boundary conditions. The model will run under interactive user control, representing operational management and strategic planning at the state and provincial level as well as market forces.

This model will be built based on qualitative descriptions of dependencies. Verbal specification of dependencies are formalized in a set of rules, a list of constraining conditions, exemptions and special cases, etc. The model is based on concepts of symbolic simulation, implemented in CommonLisp, using a frame-based, object-oriented language extension (Flavors). The major bottleneck, however, is in estimating the appropriate values and ranges for interaction coefficients, and in specifying the constraining conditions, and translating them into a set of rules through an efficient and easy-to-use knowledge acquisition module.

2.1.1 Input-Output Modeling*)

The Structure and Function of the Input–Output Model System

The Input–Output Model System (IOMS) includes several core modules. They are a static I/O module, a dynamic I/O module, a multi-objective and multi-alternative optimization module, a linear or non-linear optimization module, and a comprehensive economic simulation module. By means of these modules, a regional macro-economic development plan for a target year or for all the years from base to target year can be calculated according to the requests of users.

The principle of program design with structural modules is used in this package. This system is composed of numerous modules controlled directly by the I/O control module. In addition to the above core modules, its components also include an I/O database, objective and constraint set, an I/O module, case results storage and re-display module, maintenance module, and so on. In this system, the linear and non-linear optimization package MINOS, as well as the multi-alternative, multi-objective optimization program DISCRET can be called directly.

The structural framework of this model system is given in Figure 10.

The basic input-output model is a static type and can be expressed as the following vector equation:

$$X = AX + Y = AX + I + C + D$$

where

A - matrix of technical coefficients;

X - the total output value;

Y - the total demand, it includes:

I - investment;

C - consumption;

D - net export.

The disaggregation of the economy in Shanxi has three levels (Figure 11), each level may be conveniently coupled with another model or model set.

There are two schemes of top-level disaggregation. The first (A in Figure 12) matches the conventions used for national statistics. There are 6 aggregated sectors:

A1 Agriculture

A2 Heavy industry

A3 Light industry

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*) Section based on contributions by Ruhao Zhang, Computer Center, Planning Bureau of Shanxi Province, and Dadi Zhou, Energy Research Institute, State Economic Commission of the PRC.

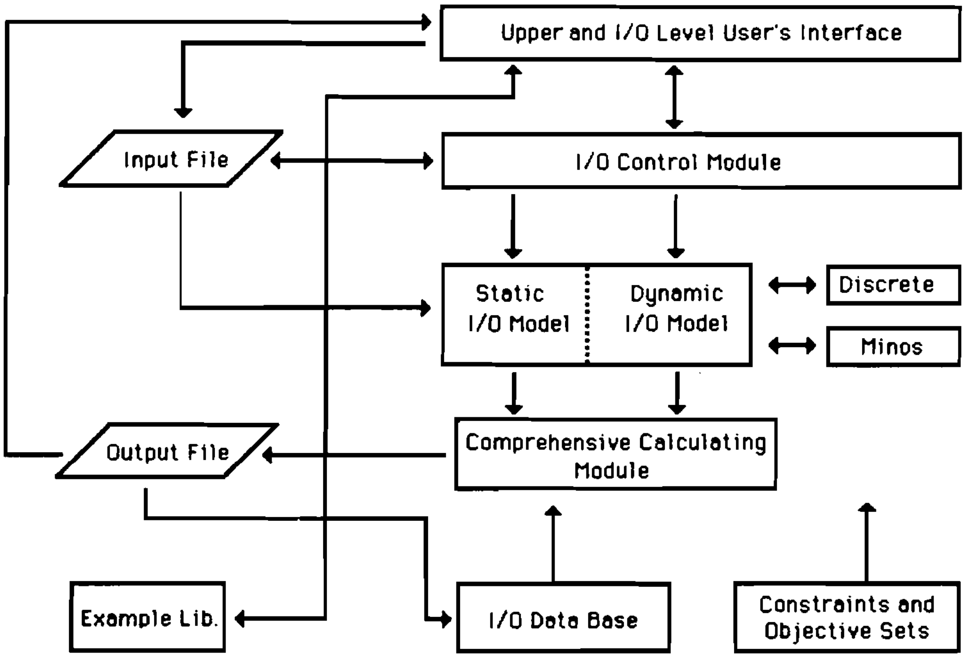

Figure 10: The structure of IOMS

A4 Construction

A5 Transportation

A6 Commerce

The second scheme is designed for the convenience of the so-called Economics of Industry (a rapidly developing discipline in economic science, especially in Japan) study. The aggregated sectors are (B in Figure 12):

B1 Primary industry

B2 Secondary industry

B3 Tertiary industry.

The relations between the aggregation at the second level, which comprises 12 aggregated sectors, and the two schemes of the first level are shown in Figure 12.

The third level consists of 22 sectors as shown below, these sectors have been aggregated from the 56 sectors in the original input-output table of Shanxi. The aggregation is as follows:

For 3 sectors

1. Primary Industry	B1.
2. Secondary Industry	B2.
3. Tertiary Industry	B3.

For 6 sectors

1. Agriculture	A1.

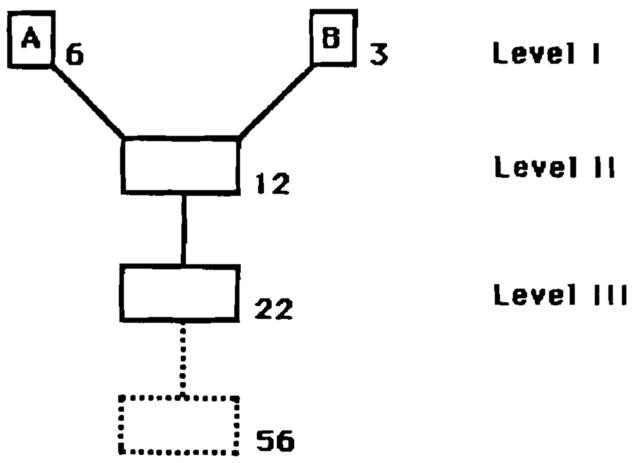

Figure 11: Aggregation levels of the input-output sectors

2. Heavy industry	A2.	
3. Light industry	A3.	
4. Construction	A4.	
5. Transportation	A5.	
6. Commerce	A6.	
For 12 sectors		
1. Agriculture	A1.1.	B1.1.
2. Coal mining	A2.1.	B1.2.
3. Mining	A2.2.	B1.3.
4. Power generation	A2.3.	B2.1.
5. Metallurgy	A2.4.	B2.2.
6. Coking & chemicals	A2.5.	B2.3.
7. Manufacturing	A2.6.	B2.4.
8. Building materials	A2.7.	B2.5.
9. Light industry	A3.1.	B2.6.
10. Construction	A4.1.	B2.7.
11. Transportation	A5.1.	B3.1.
12. Commerce	A6.1.	B3.2.
For 22 sectors		
1. Agriculture	A1.1.1.	
2. Forestry and silviculture	A1.1.2.	
3. Coal mining	A2.1.1.	

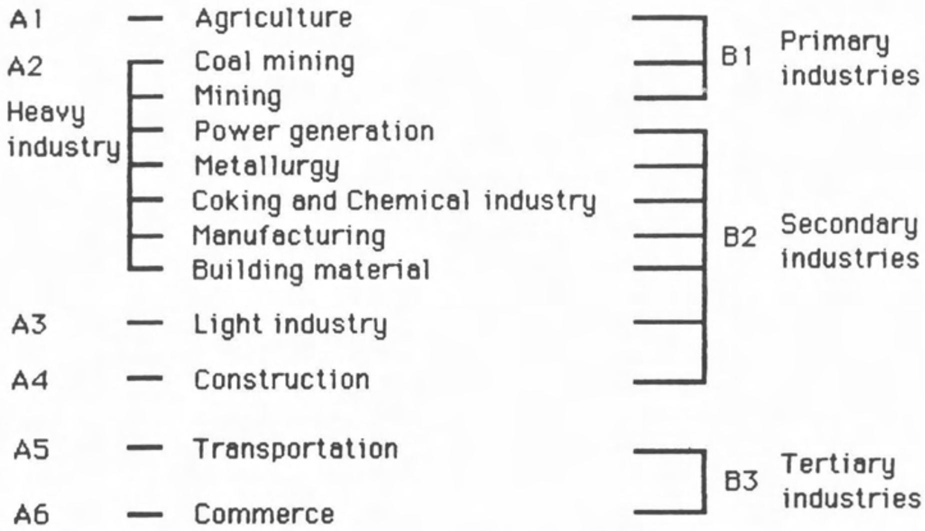

Figure 12: Input-output sector relationships for levels I and II

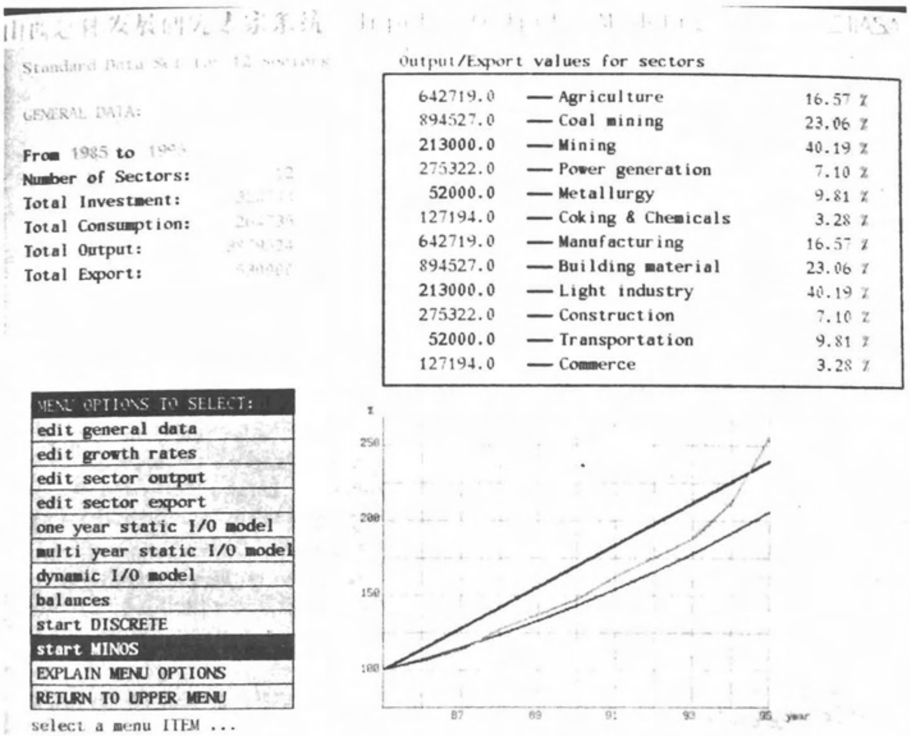

Figure 13: Summary output from a 12-sector run

4. Other mining	A2.2.1.
5. Power generation and transfer	A2.3.1.
6. Metallurgical industry(ferrous)	A2.4.1.
7. Metallurgical industry(nonferrous)	A2.4.2.
8. Coking and coal processing	A2.5.1.
9. Petroleum industry	A2.5.2.
10. Chemical industry	A2.5.3.
11. Manufacturing	A2.6.1.
12. Electronics	A2.6.2.
13. Building materials industry	A2.7.1.
14. Forest industry	A3.1.1.
15. Food production and processing	A3.1.2.
16. Textile industry	A3.1.3.
17. Other Industries	A3.1.4.
18. Building and construction	A4.1.1.
19. Transportation(railway)	A5.1.1.
20. Transportation(highway)	A5.1.2.
21. Postal services and communication	A5.1.3.
22. Trade and commerce	A6.1.1.

For 56 sectors

1. Agriculture	A1.1.1.1
2. Animal husbandry	A1.1.1.2
3. Forestry	A1.1.2.1
4. Coal mining	A2.1.1.1
5. Metal mining	A2.2.1.1
6. Chemical mining	A2.2.1.2
7. Non-metal mining	A2.2.1.3
8. Power generation and distribution	A2.3.1.1
9. Metallurgical industry(iron & steel)	A2.4.1.1
10. Metallurgical industry(nonferrous metals)	A2.4.2.1
11. Coking & chemicals	A2.5.1.1
12. Petroleum industry	A2.5.2.1
13. Basic chemicals	A2.5.3.1
14. Chemical fertilizer and pesticides	A2.5.3.2
15. Organic chemicals	A2.5.3.3
16. Pharmaceuticals	A2.5.3.4
17. Household chemicals	A2.5.3.5
18. Rubber manufacture	A2.5.3.6
19. Plastics	A2.5.3.7
20. Farm machinery	A2.6.1.1
21. Power machinery	A2.6.1.2
22. Mine machinery	A2.6.1.3
23. Chemicals machinery	A2.6.1.4
24. Light industry machinery	A2.6.1.5
25. Other industrial machinery	A2.6.1.6
26. Transportation equipment	A2.6.1.7
27. Building machinery	A2.6.1.8
28. Daily use machinery	A2.6.1.9
29. Metal goods for production	A2.6.1.10
30. Metal goods for daily use	A2.6.1.11
31. Other manufactured goods	A2.6.1.12
32. Electronics	A2.6.2.1
33. Cement	A2.7.1.1

34. Brick and lime	A2.7.1.2
35. Firebrick	A2.7.1.3
36. Glass	A2.7.1.4
37. Ceramics	A2.7.1.5
38. Forest industry	A3.1.1.1
39. Grain and oil processing	A3.1.2.1
40. Salt	A3.1.2.2
41. Food	A3.1.2.3
42. Chemical fiber	A3.1.3.1
43. Cotton textiles	A3.1.3.2
44. Other textiles	A3.1.3.3
45. Sewing products	A3.1.4.1
46. Leather products	A3.1.4.2
47. Paper	A3.1.4.3
48. Cultural & educational goods	A3.1.4.4
49. Handicrafts	A3.1.4.5
50. Sideline products	A3.1.4.6
51. Other industries	A3.1.4.7
52. Building and construction	A4.1.1.1
53. Transportation (railway)	A5.1.1.1
54. Transportation (highway)	A5.1.2.1
55. Postal services and communication	A5.1.3.1
56. Trade and commerce	A6.1.1.1

For simulation, analysis and optimization, the following socio-economic indicators have been adopted in this model set:

Name	Unit	Symbol*)
Total social output value	10^4 yuan	X
Total output value of sector i	10^4 yuan	x^i
National (regional net) income	10^4 yuan	N
Net output value of sector i	10^4 yuan	n^i
Financial income	10^4 yuan	FI
Financial payment	10^4 yuan	FP
Total investment	10^4 yuan	I
Productive investment	10^4 yuan	IP
Non-productive investment	10^4 yuan	IN
Fixed assets	10^4 yuan	K
Operational funds	10^4 yuan	F
Investment in sector i	10^4 yuan	IS
Total consumption	10^4 yuan	C
Individual consumption	10^4 yuan	CI
Profit from sector i	10^4 yuan	P_i
Taxes from sectors	10^4 yuan	fx
Wages from sectors	10^4 yuan	Wg
Net export of sectors	10^4 yuan	d
Total population	10^4 persons	P
Agricultural population	10^4 persons	PA
Non-agricultural population	10^4 persons	PN
Available labor force	10^4 persons	LF
Available agricultural labor force	10^4 persons	LFA
Available non-agricultural labor force	10^4 persons	LFN
Number of workers in sectors	10^4 persons	l
Available water resources	10^8 m^3	WR
Water consumption in sectors	10^8 m^3	W

Energy consumption in sectors	10^4 tons of coal equivalent	e
Pollution of sectors		
waste water	10^4 tons	
BOD	10^4 tons	
COD	10^4 tons	
phenol	tons	
CN	tons	
CO	tons	
NO_x	tons	
HC	tons	
dust	10^4 tons	
solid wastes	10^4 tons	
Net productivity	(yuan/man-year)	
Profit and tax rate	(%)	
Production capacity and output of main products, including:		
crops	10^4 tons	
cotton	10^4 tons	
oil crops	10^4 tons	
coal	10^4 tons	
electricity	10^8 kwh	
iron	10^4 tons	
steel	10^4 tons	
cement	10^4 tons	
wood	10^4 m^3	
chemical fertilizers	10^4 tons	

The technical coefficients a_{ij} can be adopted directly from the input-output table of Shanxi province for previous years. This model has its own database and all of the coefficients can be updated from statistics or from other (sectoral) models of the system. It can be coupled with three so-called "balance models" - that is, model of investment balance, model of material balance and model of labor force balance. These models are of an econometric type. Application of these balance models will be consistent with the traditional planning procedure.

2.1.2 I/O Modeling in a Multi-objective Optimization Framework

The I/O model in a multi-objective optimization framework is designed along the lines of DIDASS. The structure and information flow are shown in Figure 14.

Once we have the data of previous years z_0 and some rough estimations or suggestions s from the Planning Commission of Shanxi and/or from the State Planning Commission, the module "scenario generator" will be able to generate a great number of alternatives $\tilde{z}$ (major products are mainly dealt with), which will be the input to the basic I/O model module. The output $\hat{z}$ will be primarily feasible after balancing and then through the screening of constraints $g(z)$ the feasible final alternatives $\hat{z}^0$ will be obtained. The next step is comprehensive optimization and after this process, the optimization results will be obtained. Finally, through the DISCRET module, the user may select the multi-objective optimization results interactively.

The goal (objective) set $f(z)$ contains:

*) As development and implementation are still in progress the notation used here may be subject to change.

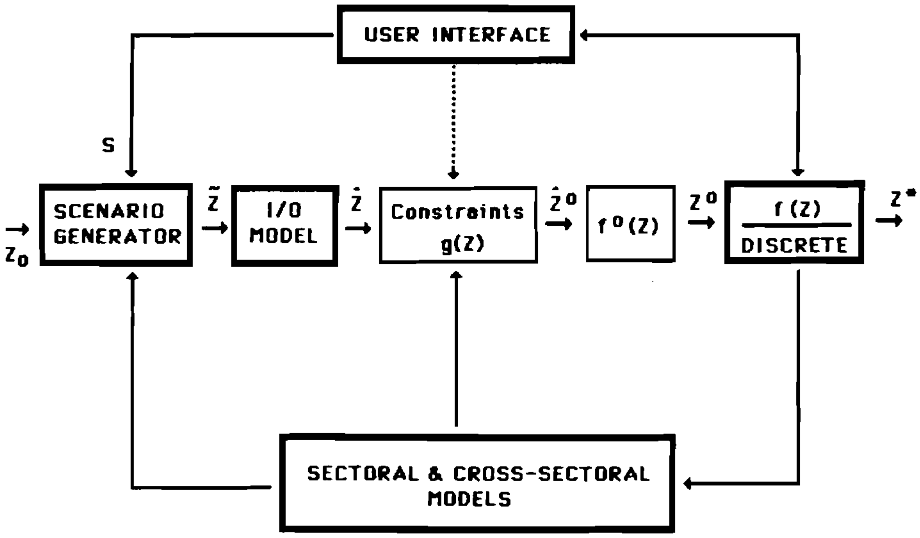

Figure 14: Structure and integration of the I/O model system

Total output value

$$X = \sum_{i=1}^{n} x_i \quad \rightarrow \max \tag{1}$$

Net output value

$$N = \sum_{j=1}^{n} |(1 - \sum_{i=1}^{n} a_{ij})\, X_i| \quad \rightarrow \max \tag{2}$$

Financial income

$$FI = a\,N + b \quad \rightarrow \max \tag{3}$$

Investment

$$I_o = \sum_{i=1}^{n} \lambda_i\,(X_i - X_{oi}) \quad \rightarrow \min \tag{4}$$

Export of products

total value	D	→ max	(5)
products	coal	→ max	
	electricity	→ max	

Energy consumption

$$\sum_{i=1,\, i \neq K_1,\, K_2 \cdots}^{n} E_i X_i \quad \rightarrow \min \tag{6}$$

Coal utilization

$$\sum_{i=1,\, i \neq K_1,\, K_2, \cdots}^{n} E'_i X_i \quad \rightarrow \max \tag{7}$$

Consumption per capita

$$\frac{C}{P} \quad \rightarrow \max \tag{8}$$

Total profit & tax rate

$$\frac{\sum_{i=1}^{n} (a_i N_i + b_i)}{\sum_{i=1}^{n} (K_i + F_i)} \quad \rightarrow \max \tag{9}$$

Labor productivity

$$\frac{\sum_{i=1} N_i}{\sum_{i=1}^{n} L_i} \quad \rightarrow \max \tag{10}$$

where

$$L_i = \frac{X_i}{\delta_i}$$

Pollution

$$P = QX = \begin{bmatrix} q_{11} & \cdots & q_{1n} \\ \vdots & & \vdots \\ q_{m1} & \cdots & q_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \quad \rightarrow \min \tag{11}$$

where $//q_{ij}//$ is the matrix of pollution.

The constraints $g(z)$ consist of:

Total output value

$$X_{\min} \leq X = \sum_{i=1}^{n} X_i \leq X_{\max} \tag{1}$$

Production capacities of sectors

$$\bar{X}_{i\,\min} \leq X_i \leq \bar{X}_{i\,\max} \tag{2}$$

Total net export

$$d_{\min} \leq \sum_{i=1}^{n} d_i \leq \bar{d}_{\max} \tag{3}$$

Net export from related sectors

$$\bar{d}_{i\,\min} \le d_i \le \bar{d}_{i\,\max} \tag{4}$$

Investment in previous year

$$I_{\min} \le I_o = \sum_{i=1}^{n} \lambda_i \,(X_i - X_{oi}) \le I_{\max} \tag{5}$$

where λ_i is the investment per unit output value in sector i.

Accumulative rate

$$\nu_{\min} \le \frac{j}{N} \le \nu_{\max} \tag{6}$$

$$N = \sum_{j=1}^{n} [X_j \,(1 - \sum_{i=1}^{n} a_{ij})]$$

Water consumption for agriculture

$$w_{1\,\min} \le w_1 = \xi_1 \, x_1 \le w_{1\,\max} \tag{7}$$

Water consumption in non-agricultural sectors

$$w'_{\min} \le w' \le \sum_{i=2}^{n} \xi_i \, x_i \le w'_{\max} \tag{8}$$

Agricultural labor forces

$$L_{1\,\min} \le L_1 \le L_{1\,\max} \tag{9}$$

Non-agricultural labor forces

$$L'_{\min} \le L' = \sum_{i=2}^{n} L_i \le L'_{\max} \tag{10}$$

Self-sufficiency in related products

$$\xi \, Y_i \le X_i \tag{11}$$

Y_i - total demand of sector i

ξ - percentage of self-sufficiency

2.1.3 A Symbolic Simulator: Approximate Simulation

For the simulation of the macro-economic development of Shanxi Province a Symbolic Simulator based on the *frame-concept* (Minsky, 1968, 1974) will be implemented.

The Macro-economic Simulation Model

The model for the regional development simulation is a dynamic simulation model, loosely following the basic ideas of system dynamics, but implemented as a symbolic, rule-driven model. The model describes the 22 aggregated macro-economic sectors at the top level (Figure 9). The sectors are described in terms of a set of descriptors and their (qualitative) relationships and interdependencies in time. These relationships are based on a set of indicator-specific cross-impact matrices, that specify the direction and relative magnitudes of the respective sector/indicator dependencies. In the model, these dependencies are represented in the form of rules.

The Concept of Symbolic Simulation

To make the implementation of the model transparent and easy to modify (which is very important in the development stage of the implementation and for future extensions) we represent the macro-economic objects as *heterarchically grouped frames communicating via a common message-distribution system.*

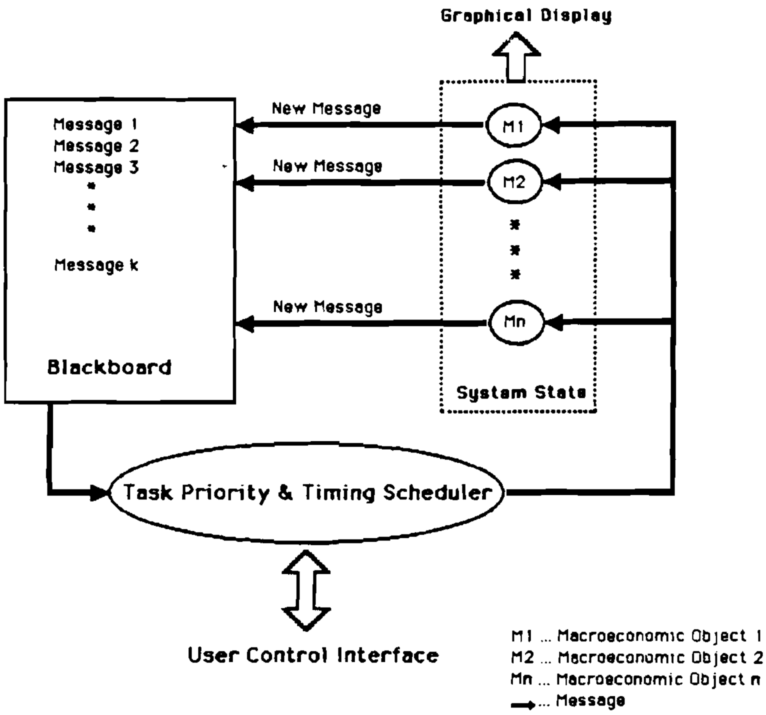

Figure 15: The layout of the Symbolic Simulator

Each *frame* consists of a number of slots that contain descriptive information as well as I/O-rules and procedural descriptions of the input/output behavior of the macro-economic object that is represented by the frame.

The heterarchical grouping of the macro-economic objects allows the objects to be defined as specializations of a number of superclasses (authorities, mining, industry, transportation, population, etc.) which comprise the default values which are used by the macro-economic objects if a slot (descriptor) does not contain an updated value. The heterarchical structure of the frame-system makes it necessary to include information about the point of view from which a macro-economic object (i.e., as a specialization of which superclass it is currently regarded) in all messages to allow the frame-system a hierarchical search for default slot value inheritance.

All messages consist of a target object name (destination), a time factor (when the message is released), a viewpoint (which superclass[es] have to be searched for inheritance of slot value defaults) and the information for the target object (output of the sending object, input of the receiving object).

The *message distribution system* consists of a *blackboard* and a *scheduler* (Erman and Lesser, 1975; Lesser and Erman, 1977). All messages that are created by the I/O-rules of the macro-economic objects are stored on the blackboard.

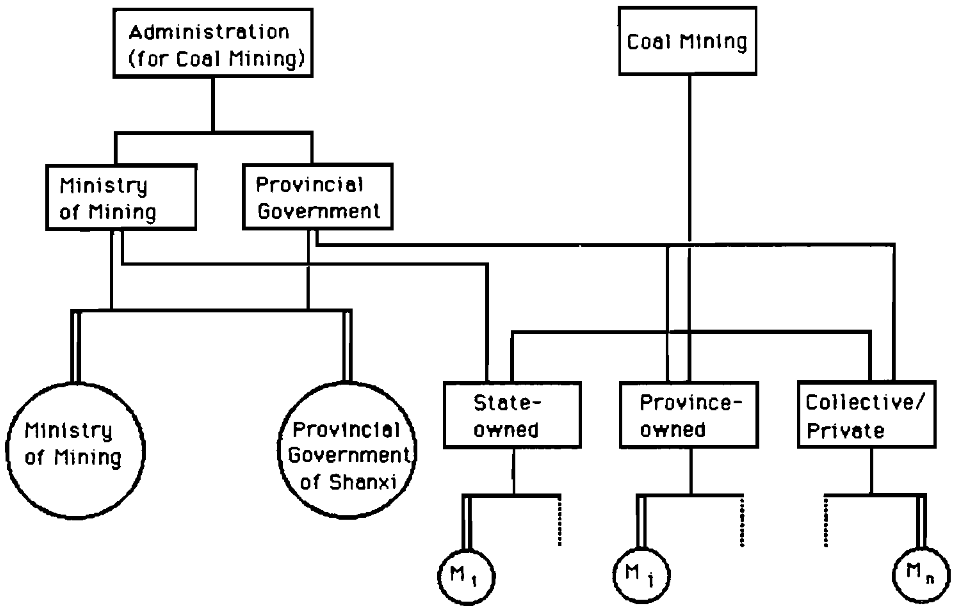

Figure 16: The heterarchical structure of the object representation

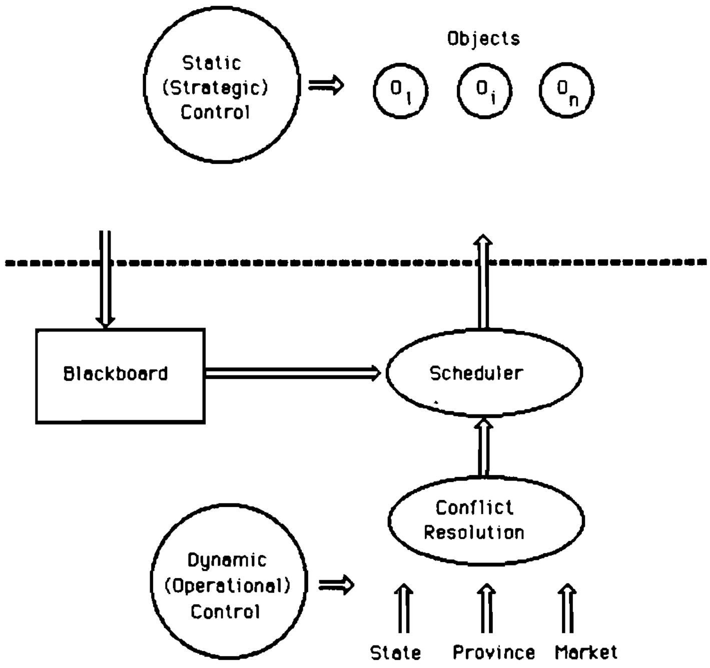

Figure 17: Dynamic versus static control structures

The scheduler scans the blackboard and selects (the macro-economic objects according to an internal priority) the message with the time factor i.e., corresponding to the current simulation time, (created and counted by the scheduler) and sends it to the target object. If there is no message with a time factor equal to the current simulation time, then the time counter is simply increased by one step by the scheduler. If there are several messages which have the same time factor that is equal to the current time then the messages are sorted according to the (scheduler-internal) priority of the target objects and then sequentially released.

By receiving a message the target object transforms the input-information to a message (output of the macro-economic object) by applying its I/O-rules, assigns a time factor (current simulation time plus the estimated duration of the I/O transformation) and a viewpoint to it and writes it on the blackboard. This recursive process lasts until an *a priori* defined end time is reached or until the user terminates the simulation.

The user interface foresees three levels of external control, representing state, provincial, and market interests and forces, respectively. They are communicated to the scheduler through a conflict resolution module, and primarily affect the priority settings of the scheduler for activating messages.

In addition to this level of external, operational and dynamic control (Figure 17), there is a corresponding system of internal, static or strategic control which is represented as part of the frame description of the individual objects.

2.2 Sectoral Models

The system integrates a number of sectoral models, concentrating on the energy sector and energy-intensive heavy industry. Three major model systems are currently being considered, namely

- **PDA** (Production–Distribution Area), a linear and spatially disaggregated optimization model that describes a broad set of industries, including mining, the energy production sector, heavy industry, chemical industry and metallurgical industries (2.2.1). The model uses an external hierarchical aggregation system that allows for selective high resolution while maintaining the model's broad coverage;
- **MAED-BI**, based on the energy demand model MAED, is a simulation model describing energy intensive industries in terms of their energy demand, basic economic behavior and investment in particular, as well as their water demand (2.2.2).
- **REPLACE**, a Prolog-based model of spatial choice and siting, which permits the exploration of feasible locations, requirements or constraints in locations for the siting of industrial or socio-economic activities in a certain region. REPLACE can be used for any or all of the economic sectors considered, and is therefore difficult to categorize as either a sectoral or intersectoral model.

All other sectors (e.g., agriculture) will, in the current development phase, be included at the level of the symbolic simulator and the input output model, respectively. The system's open architecture and modular structure, however, will make it quite straightforward and easy to integrate additional sectoral models into the system.

2.2.1 Industrial Structure Optimization: PDA*)

The model system PDA is designed to analyze and optimize industrial structures, i.e., the distribution of production capacities (and thus investments and resources) to obtain a certain set of products under specific boundary conditions (e.g., constraints on

*)This section is based on contributions by Dr. M. Zebrowski, Joint Systems Research Department, Institute for Control and Systems Engineering, Academy of Mining and Metallurgy, Cracow.

certain capacities or input materials) and minimizing or maximizing criteria such as production costs or total revenues.

The model is based on a mass conservative input/output approach, and uses mathematical programming techniques to balance the material flows connecting technological processes or installations with each other and with the outside world (sources of raw materials and markets for final products).

The model was originally designed and developed at the Institute for Control and Systems Engineering of the Academy of Mining and Metallurgy, Cracow, Poland and further developed in collaboration with IIASA's Systems and Decision Sciences Program. The model uses pre- and post-processors for interactive multi-criteria analysis based on IIASA's DIDASS programs.

The PDA model, in its current version is a linear and static tool. It will, however, be extended to considerably increase the set of technologies it can describe. Through the use of a pre-processor that allows aggregation of individual installations or sites, and a model generator, the PDA model offers a very high degree of flexibility in problem definition.

Production Distribution Area: PDA

The problem under consideration is the industrial development of a country or a region where coal is the main resource available. The output includes:

- basic chemicals like aromatics, olefines, paraffins, phenol or methanol,
- gaseous, liquid or solid fuels,
- energy, usually in the form of heat and electricity.

The set of available carbochemical conversion processes and their combinations determine the way in which the demand for products is to be met.

Apart from the carbochemical industry, the extraction of coal (the mining sector) has to be reflected in the approach. As coal of different quality could come from different sites or is exported to different markets or users, the transportation system is an important factor in these considerations. The transportation system is also of crucial importance for the distribution of products.

For the control and management of plants for coal conversion processes skilled labor is necessary. This requires taking into account the different levels of education in the labor force and their time-dependence. The operation of coal-fired power plants has to be seen in direct relation to the resource, i.e., coal. These power plants usually generate electricity, and if in the neighborhood of large cities, heat.

The development of the carbochemical industry as discussed above has to be analyzed together with the existing or developing petrochemical industry and the situation on the world market for products of these sectors and for the import of technological equipment.

Also important is the financial basis for the development process. Here it seems reasonable to distinguish between national funds (local currency) and foreign credits in convertible currency. In addition to the economic forces which usually dominate the evolving industrial structures, the environmental impacts of a coal-based industry have to be considered.

The basic linear programming model is a type of input-output model, solved by means of a linear programming package MINOS (Preckel, 1980). As a pre- and post-processor for interactive problem definition using the reference point approach, a version of the IIASA package MM (a package of the DIDASS family) is used (Kreglewski and Lewandowski, 1983).

For the Chinese case study, the original model and approach (Dobrowolski et al., 1982, 1984) is being extended into a spatially distributed version (Figure 18), (Zebrowski et al., 1987). The industrial sectors covered are represented by a simplified behavioral model (cost effectiveness of production) under a set of constraints or additional objectives (Figure 19).

The model describes the industrial system in terms of the following criteria:

- value of total production
- production costs (raw materials, labor, energy, transportation)
- investment (domestic)
- investment (foreign)
- export of coal
- export of electricity
- emissions (atmospheric pollution)
- waste water
- solid waste.

All criteria can be globally constrained. In addition to these global criteria, every individual production site has its own set of constraints (e.g., on labor at different levels of skill, availability of energy and water) and through the transportation network's capacity, linking of the individual sites (Figure 20).

To maintain the extensive coverage of technologies, ranging from coal mining to coal conversion, the energy sector, and metallurgical industries, and at the same time allow for a spatially distributed description of individual installations or sites, the model uses a pre-processor for site aggregation and a subsequent model generator. Since for several types of enterprises, e.g., small collective mines, the number of installations can reach several hundreds to thousands, individual treatment of these installations is neither feasible nor desirable. Installations of the same type (in terms of technology and scale) can therefore be aggregated into virtual sites with combined or averaged properties.

An Approach to Spatial PDA Modeling

A Spatial Production-Distribution Area (PDAS) could be defined as a large technological network-like system comprising a set of locally concentrated production networks named local PDAs. The set of local PDAs is arbitrarily determined as the widest set of possible technological alternatives reasonably pre-selected according to spatially dependent conditions.

A final choice of locations as well as technologies to be developed in the given locations is the ultimate goal of the development programming procedure. The problem of development programming without regard to spatial allocation of technology has been widely described (Dobrowolski et al., 1982, 1984, 1985; Zebrowski, 1985). The above problem will also be of concern here, as a major decision task incorporated in the framework of the development programming of PDAS.

It is important to note that transportation factors to be included in the analysis are one of several others associated with the possible spatial distribution of PDAS. Among the other factors worth mentioning are spatially allocated resources which are not transportable (e.g., land, infrastructure etc.).

Before the whole problem and its solving procedure is put down formally, it is worthwhile looking at the basic assumptions that were discerned during the problem identification:

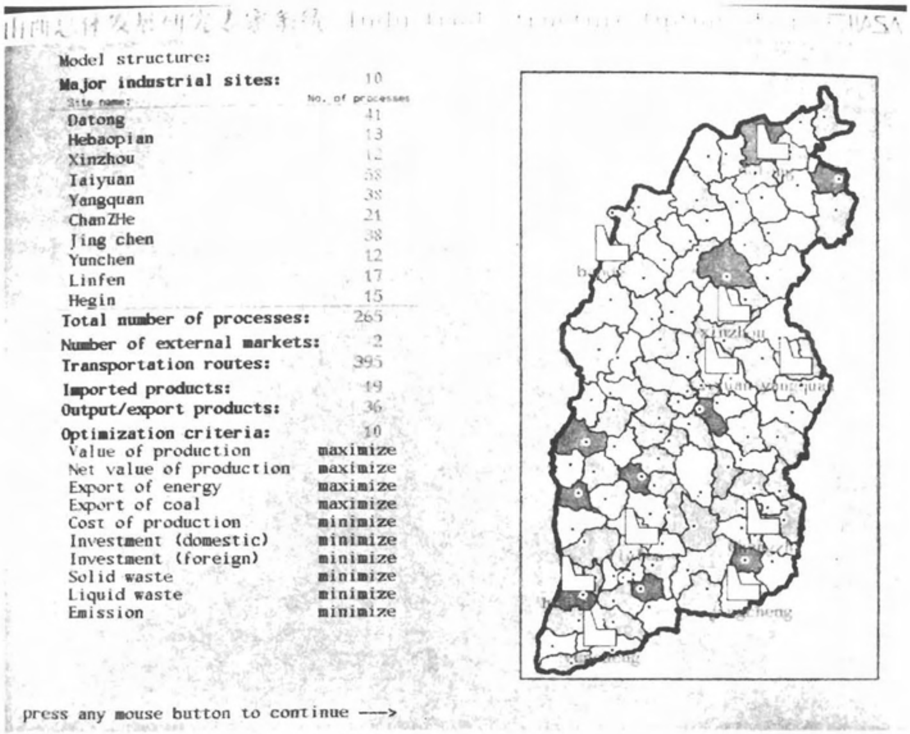

Figure 18: Startup page of the PDAS model system

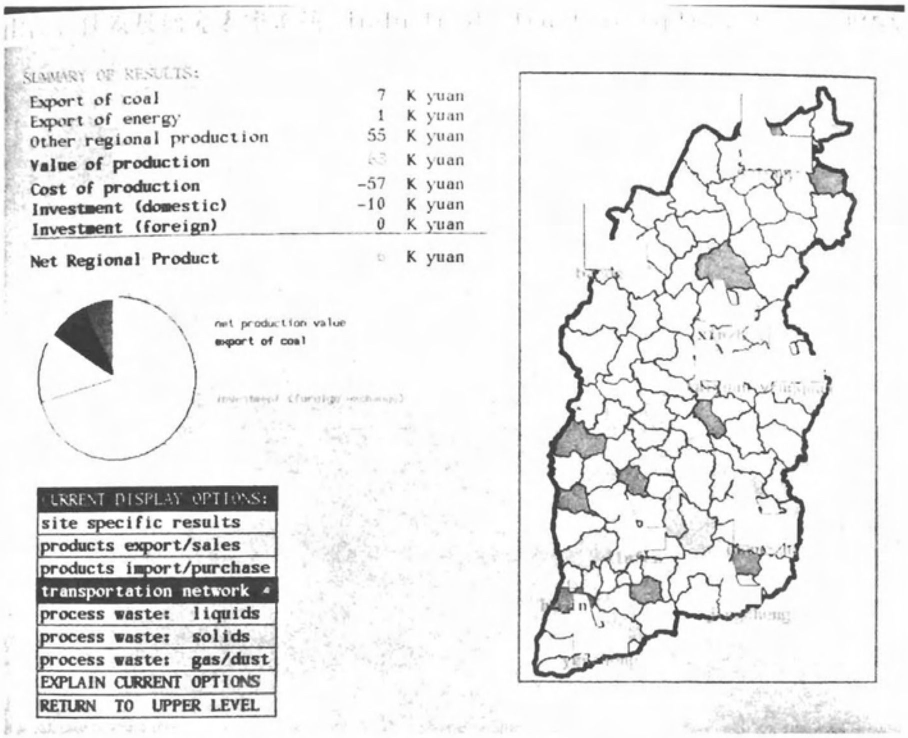

Figure 19: Summary of current optimization results

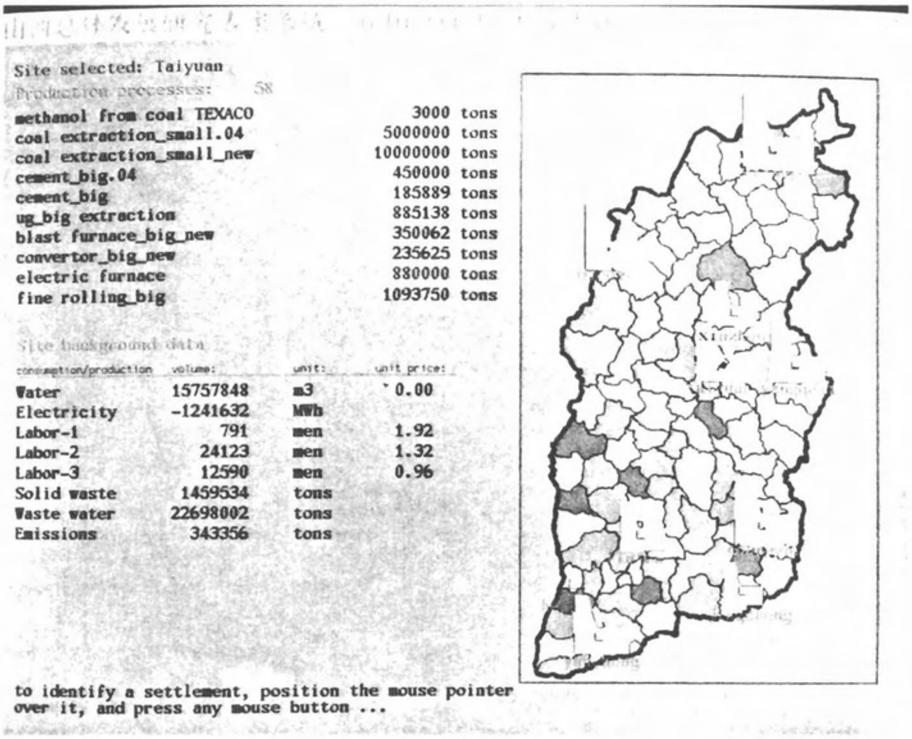

Figure 20: Site-specific results of optimization

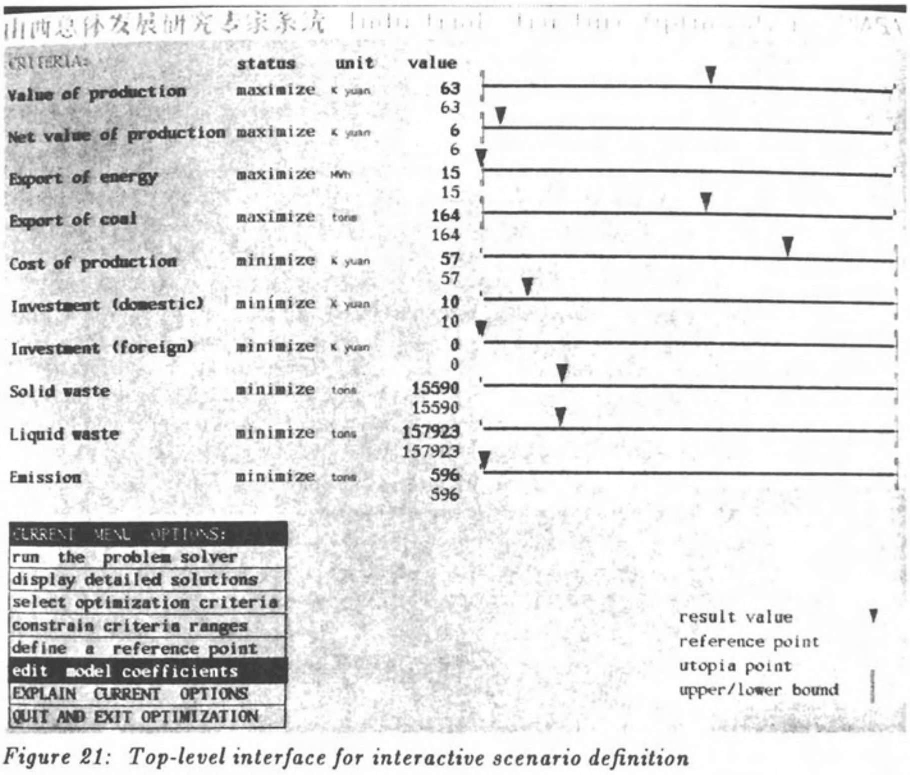

Figure 21: Top-level interface for interactive scenario definition

a) In the PDAS model, a distinction has to be made between the different kinds and the ranges of decision variables i.e., technological variables, transportation variables.

b) Transportation cost (TC) is considered as an active factor that influences the location of production units and as such is one of the PDAS structure development driving forces. Hence, the subsequent optimization problem (min TC) itself does not constitute the classical transportation problem but is a kind of location problem.

c) The transportation variables should be carefully selected in order to cut off variables of mere influence on spatial allocation of technological units. Similarly, parameters of the transportation network should be aggregated to obtain consistency between the scale of the technological model and the scale of the transportation model.

d) The PDAS model and the solving procedure should enable analysis of the parameters that determine a final solution encompassing the selected technological repertoire and location of units. In other words, the model should explain a bit better how technological and transportation conditions influence the spatial structure of the PDAS to be developed.

The above assumptions imposed strong requirements on the formal description of the problem. In keeping with points (a)and (c) above, the proposed model is a hierarchical one where the respective submodels are oriented toward technological and transportation data.

The coordination scheme of solving the whole problem enables interactive insight into the solving process. Therefore, on-line verification and modification of selected parameters is possible during computations. The idea of the two-level solving procedure is as follows:

Level 1

The problem of the overall PDAS development is formulated and solved. The identification of the problem comprises possible technological alternatives, global constraints either of a technological or economic type, as well as strategic goals of the development. Location of technological units is not taken into account at this stage of the algorithm, so only a selection of technologies that best suit conditions and goals forms a solution to the problem. More specifically, given a foreseen demand for some products, availability of resources, and economic conditions, the development program is worked out. This program is expressed in terms of capacities of production processes. Moreover, various characteristics of the solution are given according to the assumed goals (e.g., overall profit, consumption of resources).

Level 2

The overall development program (DP) of the PDAS is decomposed into a series of DPs concerning local PDAs. The decomposition is performed according to a transportation cost minimization objective. At this stage, capacities of local technological processes are determined subject to local constraints (both of the PDA and transportation type). This implies an interactive use of two models; a PDA-like model and a transportation model. A mode of the interaction, as well as communication with Level 1 is performed following a coordination procedure that makes the algorithm convergent to a suboptimal solution.

The proposed approach results in a modular structure of a DSS that has numerous advantages from the theoretical and practical point of view.

Mathematical Models

The concept discussed above could be presented as follows:

Level 1

At this level the problem of development programming is formulated within the framework of the PDA concept. Since the PDA model has been described previously in detail (Dobrowolski, 1982, 1984; Zebrowski, 1985) the PDA development programming problem (P-PDA) is only stated below in a very compact form:

P-PDA:

$$Q\,(z,y) \quad \rightarrow \quad \min \tag{1}$$

s.t.

$$G\,(z,y) \;\geq\; 0$$

where y $= \{ \; y_j \,, j \in J \supset J_t \; \}$, z $= \{ \; z_k \,, k \in K \; \}$, J is a set of indices representing chemicals, J_t denotes set of indices of substances that cause transportation cost of substantial value.

Note also that every y_j can be split into the following components:

y_j^{ms} - market sale of chemical j,
y_j^{mp} - market purchase of chemical j,
y_j^{cs} - coordinated sale of chemical j,
y_j^{cp} - coordinated purchase of chemical j,

As usual, z_k denotes production level of process k, K is a set of all technological processes in the PDAS.

To summarize, as an output of the optimization procedure at *Level 1* one obtains outflows of chemicals y_j split into y_j^{ms}, y_j^{mp}, y_j^{cs}, y_j^{cp}, $j \in J$. These variables and those associated with them, z_k , $k \in K$ represent the global direction of the whole PDAS development.

It should be emphasized that the above model holds all the assumptions of the basic PDA model, therefore it is not worthwhile quoting them here. It is obvious, however, that both the objective function(s) and type of constraints that occur in the PDAS version are implementation specific.

Models of local PDAs have an analogous form. They are distinguished from the general PDAS model by the superscript l designating all components of the model.

Level 2

Denote L as a set of possible locations of local PDAs. Chemical substances that are consumed in technological processes in a given location can be either produced in the same local PDA, other local PDAs, or can be purchased on the market beyond the whole PDA. Moreover, between given sites, chemicals can be transported along different routes that have different transportation costs.

The entire transportation cost in the whole PDAS can be evaluated according to the following formula:

$$TC = \sum_{j \in J_t} \sum_{l \in L} \Big[\sum_{n \in L} \sum_{r \in R_{nl}} x_{jr}\, d_r\, P_{jr} + \sum_{m \in M} \sum_{r \in R_{lm}} v_{jr}\, d_r\, P_{jr} \Big] \tag{2}$$

where:

J_t - set of chemicals that cause meaningful transportation cost,

R_{nl}, R_{lm} - set of routes that connect locations n,l and l,m

x_{jr} - amount of substance j transported by the route r,

M - set of markets,

v_{jr} - amount of substance j imported and/or exported by the route r,

d_r - distance along r,

P_{jr} - price for transportation of unit product j along route r.

In order to formulate an optimization problem for minimization of TC, the following constraints are taken into account:

$$\sum_{l \in L} \sum_{r \in R_{ml}} v_{jr} \leq V_j^m \tag{3}$$

$$\sum_{l \in L} \sum_{r \in R_{lm}} v_{jr} \leq S_j^m \tag{4}$$

$$\sum_{j \in J_t} \sum_{l \in L} \sum_{n \in L} \sum_{r \in R_{lm}} x_{jr} \leq T \tag{5}$$

$$\sum_{l \in L} \sum_{n \in L} \sum_{r \in R_{lm}} x_{jr} \leq t_j \text{ , } j \in J_t \tag{6}$$

$$\sum_{j \in J_t} x_{jr} \leq R_r \tag{7}$$

where:

V_j^m - availability of substance j from market m,

S_j^m - saleability of substance j from market m,

T - total transportation potential,

t_j - transportability of substance j,

R_r - maximal transportation flow along route r

It is important to observe that the above model has a natural connection with the PDA model, because the following equations hold:

$$\sum_{n \in L} \sum_{r \in R_{ln}} x_{jr} = y_j^{l\ cs}, \tag{8}$$

$$\sum_{m \in M} \sum_{r \in R_{lm}} v_{jr} = y_j^{l\ ms}, \tag{9}$$

$$\sum_{n \in L} \sum_{r \in R_{nl}} x_{jr} = y_j^{l\ cp}, \tag{10}$$

$$\sum_{m \in M} \sum_{r \in R_{ml}} v_{jr} = y_j^{l\ mp}, \tag{11}$$

where $y_j^{l\ cs}$, $y_j^{l\ cp}$, $y_j^{l\ ms}$, $y_j^{l\ mp}$, $l \in L$, denote spatial coordinates of vectors y_j^{cs}, y_j^{cp}, y_j^{ms}, y_j^{mp}.

As follows from the above observation, the solution to the transportation problem (P-TR) can provide a feasible decomposition of the PDA model outputs (y^{cs}, y_j^{cp}, y_j^{ms}, y_j^{mp}), as far as the conditions:

$$\sum_{l \in L} y_j^{l\ cs} \leq y_j^{cs}, \tag{12}$$

$$\sum_{l \in L} y_j^{l\ ms} \leq y_j^{ms}, \tag{13}$$

$$\sum_{l \in L} y_j^{l\,cp} \leq y_j^{cp}, \tag{14}$$

$$\sum_{l \in L} y_j^{l\,mp} \leq y_j^{mp}, \tag{15}$$

are assumed to hold for the transportation problem.

In concluding, the transportation problem consists of the objective (2), transportation constraints (3)-(7) and linking constraints with the PDA model (8)-(15). The latter are put down in a redundant form to visualize the link between the two models better.

It is important to note, however, that the above spatial decomposition of the global solution takes into account only transportation factors and as such neglects local circumstances that may influence technological development of the local PDAs. For the above reason, a coordination procedure that combines solutions derived from the PDA and the transportation model is worked out.

Solving Algorithm

The proposed algorithm consists of the following steps:

Step 1.

Generation of the overall PDAS development program, i.e., determination of the variables $\{y_j,\ j \in J\}$, $\{z_k,\ k \in K\}$. For further considerations the set K (potential technologies) will be always limited to those selected by non-zero variables z_k (K = $\{k;\ z_k\ 0\}$).

Step 2

Solving the problems regarding development of local PDAs (P-PDA^l, $l \in L$) ;

$P-PDA^l$:

$$Q^l\,(z^{l,y^l}) \quad \rightarrow \quad \min \tag{16}$$

s.t.

$$G^l\,(z^{l,y^l}) \geq 0$$

where G^l represents also a set of local constraints on resources (manpower, water, energy etc.). The solution obtained at this step is $\hat{y}^l$, $\hat{z}^l$.

Step 3

Solving the transportation problem P-TR;

$$TC\,(x,y,z) \quad \rightarrow \quad \min \tag{17}$$

s.t.

$$y = \left\{ y_j^l, \sum_{l \in L} y_j^l \leq y_j,\ j \in J_t \ \text{ and } \ y_j^l \leq \hat{y}_j^l \right\}$$

The solution to the above problem $y_j^l = \tilde{y}_j^l$ will be used in the next step.

Step 4

Choice of the PDA^l that satisfies the following condition:

$$\left|\left| \hat{y}_j^l - \tilde{y}_j^l \right|\right| \quad \rightarrow \quad \min \tag{18}$$

The solution is $l = s$.

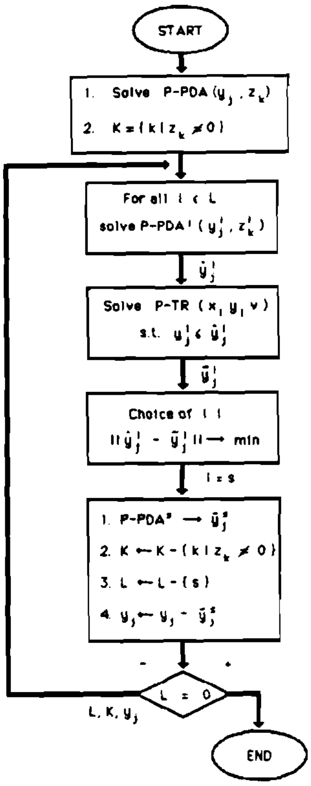

Figure 22: The solving algorithm

Step 5

Generating the eventual optimal structure of the PDA^l through solving the PDA^s, s.t. additional constraint $y_j^s \leq \hat{y}_j^s$. The solution is denoted $\bar{y}_j^s$, then y_j obtained from solving P-PDA is updated (y_j <-- $y_j - \bar{y}_j^s$). The selected set of technologies K^s will be subtracted from the set K (K <-- K - K^s). Similarly, L will be diminished by s (L <-- L - s).

If $L = 0$, go to step 2, otherwise the procedure is terminated.

The algorithm presented above takes advantage of a natural decomposition of the problem when two factors, i.e. transportation cost and local constraints often happen to be inconsistent driving forces of a spatial development of the industrial structure.

2.2.2 Energy Intensive Industries: MAED-BI

MAED-BI (Model for Analysis of the Energy Demand - Basic Industries) is an accounting model which improves the effectiveness of the already existing MAED *) model in the two following areas:

*) MAED __ MAEDI Version, Users' Manual, Section of Economic Studies, Division of Nuclear Power, International Atomic Energy Agency (IAEA), Vienna (1983).

- the treatment of basic industries,
- the link with the macro-economic level of each country or region studied.

MAED-BI, which can integrate a large number of products, was conceived on a rather exhaustive basis so as to fit the specific development aspirations of any developing country in basic industrial sectors.

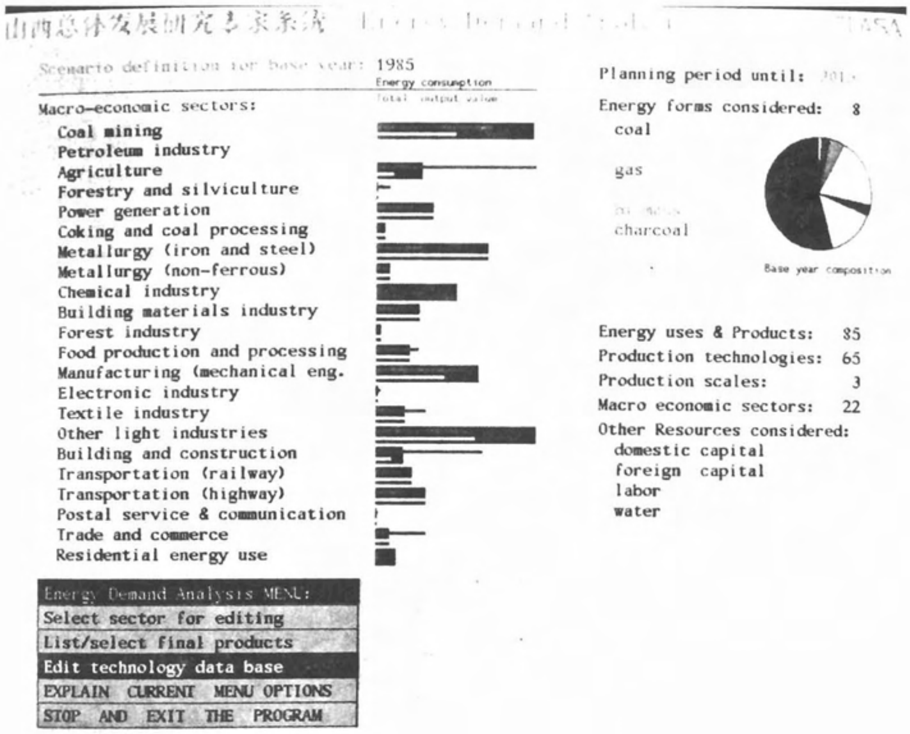

Figure 23: Scenario definition for the energy demand analysis model: sector selection

Three scale levels, and within them, capacity exponents, can be selected in order to render economies of scale and technological discontinuities which occur between the possible capacity sizes at which a given production can take place. Specifically, by taking into account the huge potential of economies of scale, the model can describe discontinuous patterns of output growth in basic industries.

These extensive possibilities for scenario definition do not have to be used systematically (and in fact very few developing countries would have a chance to cover the whole range of products in the foreseeable future), but have to be selected in accordance with the particular context of the country.

MAED is used in an interactive and iterative procedure: First, the user defines a preliminary development scenario (which may be technologically inconsistent); MAED then transforms this scenario, if necessary, according to its internal constraints (e.g., technological constraints); the refined and consistent scenario is then analyzed, the output presented to the user; in the last step, the user will then have to assess the output

For the MEDEE methodology used in MAED, see B. Chateau, B. Lapillone, *Energy Demand: Facts and Trends*, Springer-Verlag, Vienna, 1982.

within the framework of the overall external macro-economic constraints, possibly by feeding MAED's output back into the input-output model (see 2.1) or into one of the above industrial structure optimization models (section 2.2.1), or by evaluating with a cross-sectoral model, e.g., transportation or water resources (section 2.3.1, 2.3.2).

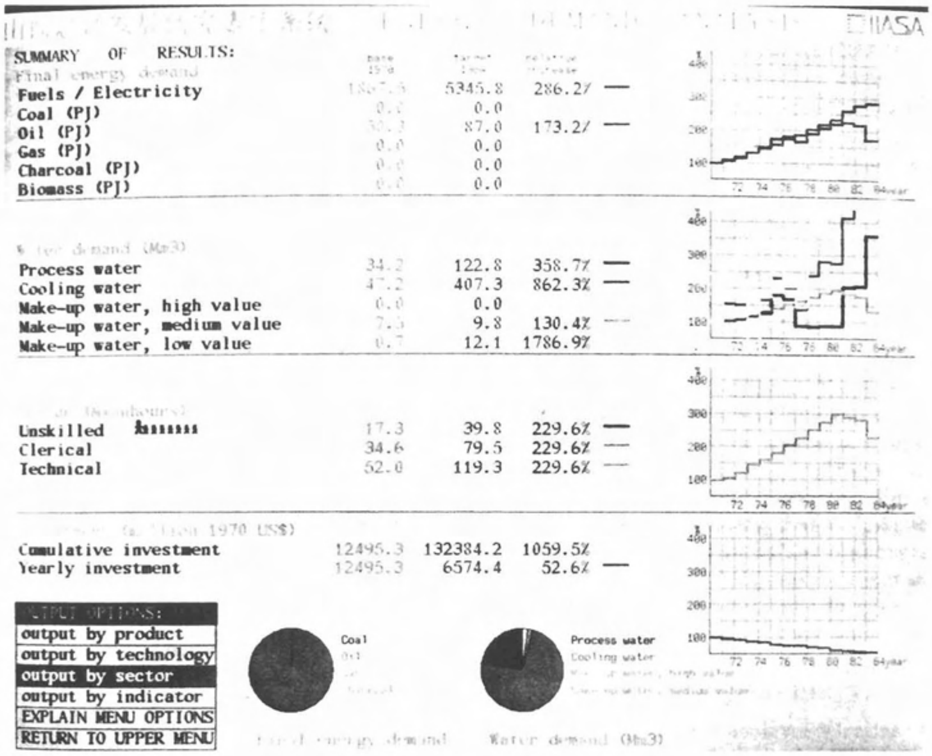

Figure 24: Summary output from MAED

The absence of an optimization procedure in MAED-BI compels the user to formulate a precise statement of what is required for future industrial development. The model requires that this development scenario be organized in a set of hierarchical exogenous hypotheses. The model input consists of one such development scenario formulated in terms of:

- industries to be considered (iron and steel, non-ferrous metals, chemicals, cement, tiles and bricks, glass, pulp and paper);
- scale levels to be considered (large, medium and small);
- final products to be considered (currently 32, of which 20 are chemicals including 8 types of fertilizer);
- choice of technologies to be used (which determines the intermediate products and raw materials to be considered);
- breakdown of the products into tradable and non-tradable products;
- level of import and export for tradable products;
- level of domestic demand for the final products.

For each such scenario, the model output describes:

- energy demand by industry and type (electricity, coal, gas, etc.);
- water demand;
- capital requirements (for construction);
- skilled labor requirements (for operation).

MAED-BI aims neither to deterministically forecast the future development of national basic industries, nor to find a hypothetical optimum development for them. It is, rather, conceived as a tool for interactive scenarios analysis.

When dealing with basic industries, energy demand, capital and educational requirements have to be taken into account. They are therefore the central variables of the model. Nevertheless, some additional analysis, on water utilization and pollution, land use, etc., are also possible in the framework of MAED-BI, due to its highly disaggregated structure. Thus MAED-BI must be seen as an accounting tool which aims at discerning strategies which are acceptable with regard to a certain number of constraints (energy supply, capital, manpower and environment). Since these constraints apply globally and with low elasticity (e.g., water) to cumulative developments, they are basic boundary conditions for long-term development.

In itself MAED-BI does not incorporate any explicit economic evaluation. This must be done at two different phases. First, by defining for each of the basic industrial sectors a strategy which integrates expert knowledge of the available potential of sectoral growth. This requires a global survey from raw materials resources to final demand prospects and may hardly be modeled; it has to constitute the core of the "scenario" which gathers the exogenous inputs required for running MAED-BI. Second, the trends revealed in the industrial sectors described in the model have to be compared to a macro-economic development simulation (see section 2.1.) in order to judge the feasibility of the solution vis a vis external macro-economic constraints. Areas for such interactions are the following:

- activity levels of basic and mining industries (measured in tons of products in MAED-BI and generally in monetary units in economic models);
- activity level of the energy sector (MAED calculates the global energy demand in tons of oil equivalent);
- capital formation and investment (MAED-BI builds up an indicator of current gross capital formation in basic industries).

In other areas covered by MAED-BI, such as skilled labor and educational requirements, water use, etc., the results of the model may be used by the experts concerned to make a comparative evaluation against their own intuitive judgement.

The final results of these comparisons may lead to a reformulation of the scenario so as to release the current constraints. Then, in an interactive procedure, a new run can be performed.

For a larger number of products to be considered simultaneously, the definition of a scenario of demands in time and the corresponding technological network becomes a very complicated and demanding task. We are therefore exploring the possibility of providing a default industrial technology network, generated automatically, based on a set of strategic preferences defined by the user. The automatic generation of a technology network will be implemented in Prolog. It is based on a matching procedure between a user defined set of strategic preferences for certain technologies (such as, for example, a preference for technologies with a low investment requirement, medium to low water consumption, small scale installations, etc.); as well as the specific properties of individual technologies. These properties of alternative technologies are represented in qualitative terms, such as, e.g., large water consumption, small investment requirements, very high skilled labor requirement, large environmental impact. Clearly, the matching

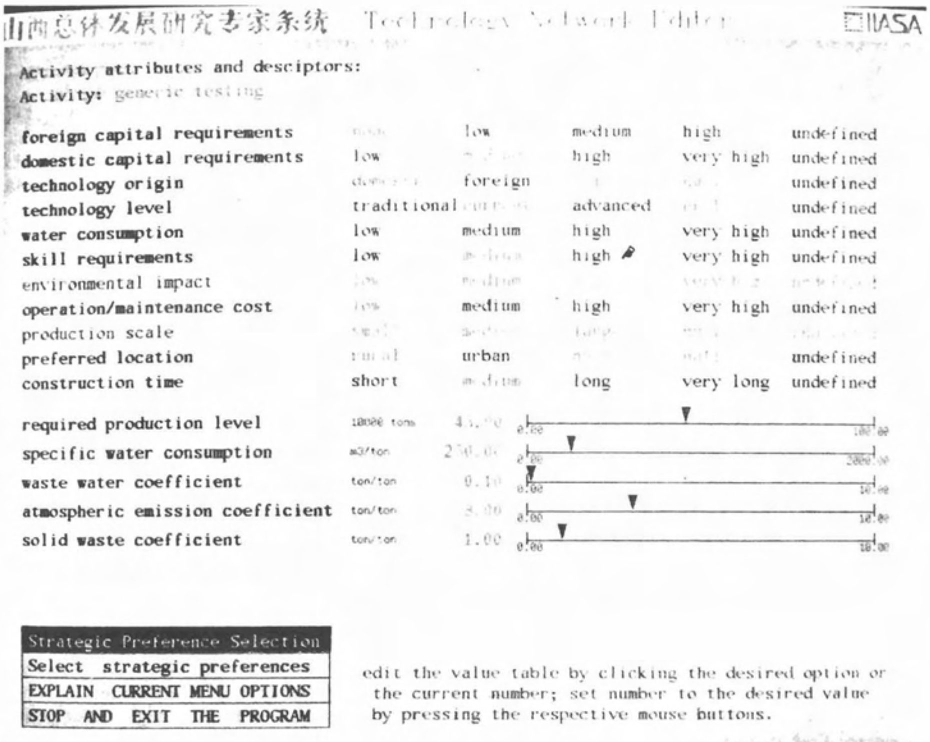

Figure 25: Interface example for strategic preference selection

mechanism has to consider not only individual technology alternatives, but the entire complex technological network for evaluation and selection based on the user's preferences.

2.2.3 Locational Analysis and Site Selection: REPLACE

REPLACE is a computational approach to spatial choice modeling. It presents a methodology and software application for developing computational models that could be applied in a reconstructive analysis of spatial choice or for strategic site selection. The basic argument underlying the so-called relational analysis is that in order to become a member of the choice set (i.e., a feasible location for an industrial or socio-economic activity), the choice object should have properties which match the requirements as resulting from the characteristics of an actor (the above activity) whose choice process is to be modeled, as well as that the actor should fulfill certain requirements or constraints caused by the properties of the object.

The reconstructive or strategic planning model is equipped with knowledge about the qualitative and quantitative aspects constraining spatial choice (the declarative part) while a computational tree search procedure is used to find a set of objects satisfying the requirements by an actor as they are deduced during the inference (the procedural part).

Both the knowledge representation part and the search procedures are implemented in Prolog, a language which combines programming in first order predicate logic with database management.

For the first implementation, the resolution of the locations will be at the level of counties (and possibly specific towns within counties). Activities to be considered range from industrial enterprises (coal mines, power plants, iron and steel works, chemical industries) to non-industrial activities such as airports, high schools, or large hospitals.

2.2.4 Agricultural Development: Investment and Technologies

At this point, no specific agricultural model is foreseen in the current IIASA/SSTCC project. The treatment of agriculture is therefore restricted to

- the input/output model;
- the symbolic simulator;
- the water resources model.

In the latter case, the water allocation must consider the revenues and, more generally, socio-economic consequences of water use. Since industry and agriculture, in many cases, compete for water, the water-derived benefits for various types of use have to be evaluated and compared together with the costs of alternative water conservation strategies.

In particular, this part of the water allocation component of the river basin simulator MITSIM (see 2.3.2) could evaluate costs and benefits of alternative irrigation technologies for agriculture, which promise considerable water savings. The investment requirements can then be compared against the potential increase of revenues from industrial production, that could use the water saved by agriculture. Since the agricultural water demand amounts to 70% of the overall water use, the potential for conservation and re-distribution is considerable.

The implementation could be based on an iterative structure of heuristic allocation rules, that scan the various irrigation technology alternatives and rank them under a set of user-supplied preferences.

The importance of agricultural production, and especially the grain production in Shanxi's economy is evident, although it amounts to only 25% of total output value. The sufficient supply of food is an important factor not only for economic growth, but also for social stability. In a next project phase, a set of specific models for agriculture and rural economy could be built into the system.

Agriculture, in a broad sense, includes the production of crops, forestry, animal husbandry, and sideline products, usually on the basis of agricultural raw materials. In the rural economy, besides agriculture, the rural industry plays an important role for economic growth. For the study of the rural economy's infrastructure, a model set should be designed firstly to analyze the proportion and structure of agriculture and rural industry. For agricultural production per se, a subset of models is required to simulate and optimize the production process under different investment conditions, technologies, and resource utilization patterns (e.g., land, water, fertilizers, labor). An important indicator and constraint is the degree of self-sufficiency of the province.

2.3 Cross-sectoral Models

The major cross-sectoral models included in the prototype system are a water resources model and models of environmental impacts of industrial development on air and water. These models are linked to the corresponding sectoral models of industrial development. They either provide constraints as in the case of the water resources model, or translate emissions estimated at the industrial production level into environmental quality indicators such as air and water pollution figures.

The transportation system as well as the population sector are primarily represented at the level of the symbolic simulator.

2.3.1 The Transportation System

The transportation system is tightly interwoven with the spatially distributed representation of industrial production (section 2.2.1 above). In the PDA model, it is represented as a matrix of unit transportation costs as well as capacity constraints. If the PDA model runs against such a capacity constraint, this is signaled to the user, who can then, external to the PDA model, estimate the costs of a capacity extension for this specific branch of the transportation system, and update the corresponding cost and capacity information for the PDA model. Methods to support a simple estimation procedure (e.g., Manheim, 1979) are under discussion.

Clearly, given the importance of the transportation problem in Shanxi, a set of specific transportation models, addressing, in particular, the investment problems of spatially distributed development, should be included in the system.

2.3.2 Water Resources: Optimal Allocation of a Scarce Resource*)

The framework for the description of the water resources system is based on the MITSIM model developed at MIT (Lenton and Strzepek, 1977; Strzepek and Lenton, 1978), which also has a considerable history of successful applications in countries such as Argentina, Nigeria, Cyprus, Israel, Egypt, India, Sri Lanka, PRC (Yellow River), Thailand, as well as in Colorado and Texas, USA.

MITSIM is a variable time-step, Monte Carlo, hydro-economic simulation model that operates on the basis of hydrographical catchments or river systems, including the groundwater system. Its purpose is a stochastic analysis of the hydrologic and economic performance of water resource development projects in the context of the river basin system. It was used to fine-tune development plans proposed by a deterministic screening model and later singly as a screening and analytic tool.

In 1974, the model was revised and improved. These improvements made it more general and added greater input error checking, with subsequent improvements in 1976 to the model's economic analysis capabilities. In addition, a new version, MITSIM-GW was developed, which allowed analysis of conjunctive use by coupling the surface water model with a numerical groundwater simulation model. Further revisions were made in 1986, reflecting requests by users over the past ten years. These revisions include variable time-steps within a simulation year from 7 days to several months, more detailed modeling of reservoirs and hydropower plants, irrigation areas, and river diversions, downstream priority, flow routing over long river reaches, and modeling of the appropriative rights doctrine for water allocation.

MITSIM allows for the hydrologic assessment of water development plans involving varying configurations of structures, water use, and performance target levels. The model can assess the future hydrologic and economic impacts of alternative river basin development plans, thus allowing a planner to evaluate the effects of various systems of irrigation areas, municipal and industrial (M&I) projects, reservoirs, power plants, and diversions. Hydrologic reliability, expressed in terms of the percentage of the time that performance criteria are met, is developed as output to the program, by simulating the river system response to varying streamflow inputs over time, and may be calculated for any project or set of projects within the system being modeled.

Economic effects are measured in terms of the net economic benefits, the benefit cost ratio, and the internal rate of return of the different planning options. The model also provides for the measure of agricultural employment generated by these planning alternatives. With MITSIM, such evaluations may be made for the entire river basin

*) Section contributed by Dr. Kenneth M. Strzepek, Director, Center for Advanced Decision Support for Water and Environmental Systems, College of Engineering and Applied Science, University of Colorado at Boulder, Boulder, Colorado 80309-0428, USA.

under analysis, for a region or sub-basin within the larger river basin, or for specified sets of these sub-basins. In addition, this information may be generated as output for any or all of the individual projects in the river system, whether existing or proposed.

A river basin is described as a system of arcs and nodes. A node represents a structural or non-structural component (e.g., reservoir, irrigation site, power plant, confluence, groundwater extraction, etc.) of the river system. Nodes are linked by arcs or reaches, describing natural or man-made connections in the river system. The model traces water flow through the system in space and time, and keeps track of the costs and benefits resulting from the use of the water. Estimates of the reliability of supply versus a specified temporal and spatial demand structure can be obtained.

The basic operation of the model consists of the calculation of the monthly flow at all nodes of the basin for all simulation periods, by simply sequentially calculating flows at each node from the starting nodes of the system to the terminal node(s), considering inflow, consumption, and groundwater extraction. At nodes with consumption, the appropriate amount of water is subtracted from the system, and converted into the designated economic activity. More generally, nodes are locations where some accounting of flow must be made for either economic or hydrologic purposes. A location where water is diverted from the river for a trans-basin diversion offers a clear picture of what may happen at a node. Here, accounting is necessary - water is being lost to the system and the loss must be noted. Another location where accounting is necessary is at an irrigation area. The loss here due to consumptive use must be recorded.

Not all nodes involve an accounting to record loss from the system. Nodes must be established for significant inflows to a stream, whether from snowmelt, rainfall, or irrigation return flow (which may be fed from groundwater extraction). The node for a reservoir may record the change in flow according to whether the reservoir is storing or releasing water. Often it is desirable, or necessary, just to monitor the flow at a location. Here, neither loss, gain, nor change in flow are measured, but an accounting of flow may be required to assess the performance of, say, a run-of-the-river power plant at that location, or to evaluate what percent of the time flow requirements are met for fish and wildlife, navigational, or recreational purposes.

Arcs are used to represent the hydraulic connections between the nodes. Flow leaving a node passes (symbolically) along the arc and arrives unchanged at the next node. No accounting needs to be made for any arc. The arc serves for schematic purposes only. It allows the user to see the route of the stream flow and to establish relative locations of the nodes. This is necessary in order that the user may develop input information which will be used by MITSIM to route the water from node to node in proper sequence. It is also necessary for the development of information which will allow MITSIM to respond to the imperatives of prior appropriation should the modeling be undertaken where water is allocated on this basis.

In order that the simulation may proceed, each year is divided into intervals which are referred to as time-steps or seasons. These are time intervals in which, for planning purposes, it can be assumed that the conditions being modeled are constant. The input to MITSIM describes the hydrologic, physical, and operating features of each node. This nodal input is made for each time-step. Time-steps may vary in length from one week to one year. Hydrologic input for each node is processed and then combined with economic input data for the nodes. MITSIM then generates the hydrologic and economic output described above.

The node-arc system is used in MITSIM because it permits, in successive simulations, alteration of the system being modeled without changing all the input describing the system. This is because each node is described individually by the input data. By changing the system of node connectivity described by the arcs (specified as input data for each node), and by adding or deleting as needed, data input for certain nodes, a completely new planning configuration may be modeled with relatively little effort. The size of the system MITSIM can model is a function of the computer system on which it is running.

In most real-world situations, ground and surface water sources conjunctively supply agricultural, municipal, and industrial water demand. Deficits in the supply from one source can be alleviated by supplements from the other.

In its groundwater version, MITSIM-GW includes a detailed consideration of groundwater as a sole source of water supply, or as used in conjunction with surface water. The groundwater part of the model adds groundwater aquifer storage levels, reliability of groundwater supply, and groundwater supply costs and associated benefits.

The description of groundwater flow in an aquifer and its pumping fields is based on an irregular multi-cell discretization with distributed parameters, using implicit numerical integration. As an extreme case, an aquifer can also be represented as a lumped system.

The Fen River Study and Future Developments

In the Shanxi Province Case Study, MITSIM-GW will be implemented for the Fen river basin. A graphics interface will allow for quick and accurate input of data for MITSIM and provide comprehensive presentation of simulation results at various levels of detail to offer analysts the maximum use of simulation analysis techniques.

MITSIM will be connected with the macro-economic as well as the sectoral models (e.g., PDAS and MAED). These economic models will provide water demands that will be analyzed by MITSIM. Results from the MITSIM analyses will then be fed back to the economic models and an iterative process will continue until a satisfactory allocation has been proposed.

An important extension to the basic bookkeeping mode of operation would be in the simulation of allocation strategies, i.e., re-distribution of water according to e.g., the value added by production based on water. An obvious problem here is the competition for water between agriculture and industry, where the additional industrial revenues (from using more water) could, in part, be used to finance water conservation strategies for agriculture (canal lining, different irrigation practices). Another option that can be explored with the model is inter-basin transfer, e.g. feeding water from the Yellow River into the Fen basin.

A problem to be addressed is the explicit treatment of groundwater. A considerable degree of the industrial water demand is currently satisfied from groundwater resources. Given the ambitious development objectives of the region, severe overexploitation and local competition for the groundwater resources is a likely scenario. The spatially distributed groundwater component of MITSIM that estimates the effects of withdrawals distributed in time and space is an important component of the MITSIM framework.

2.3.3 Environmental Quality: Air, Water, Soil

To describe atmospheric dispersion in a more dètailed, dynamic, and possibly site-specific way, the Industrial Source Complex Model (ISC) developed by the U.S. Environmental Protection Agency (EPA) is foreseen for inclusion in the software system. It is based on an extended Gaussian plume equation of Pasquill (1961), describing the concentration/deposition of substances in time and space.

The *ISC Long-Term Model* (ISCLT) is designed to calculate the average seasonal and/or annual ground-level concentration or total deposition from multiple continuous points, volume and/or area sources.

The *ISC Short-Term Model* (ISCST) is designed to calculate ground-level concentration or deposition from stack, volume or area sources. The receptors at which the concentration or deposition are calculated are defined on a x-y, right-handed Cartesian coordinate system grid. Discrete or arbitrarily placed receptors may be defined. Average concentration or total deposition may be calculated in 1-, 2-, 3-, 4-, 6-, 8-, 12-, and/or 24-hour time periods. An 'n'-day average concentration (or total deposition) or an average concentration (or total deposition) over the total number of hours may also be computed. Concentrations (depositions) may be computed for all sources or for any combination of sources the user desires. Other options include input of terrain heights for receptors, tables of highest and second highest concentrations or depositions at each receptor and tables of the fifty maximum values calculated.

Other extensions of the Gaussian Model include:

- the influence of urban or rural area on the weather;
- plume rise (Briggs 1971, 1975);
- variable topography of the area, influencing the variation of wind and temperature;
- the influence of buildings close to the source (Huber and Snyder, 1976; Huber 1977), affecting the coefficient of dispersion;
- the exponential decomposition of chemicals;
- a simple deposition model (Dumbauld et al., 1976; Cramer et al., 1972).

Given the limitations of the available data, this model will currently be implemented for the Taiyuan area only (Figure 26). Clearly, a generalization and implementation to several other industrial centers would be useful.

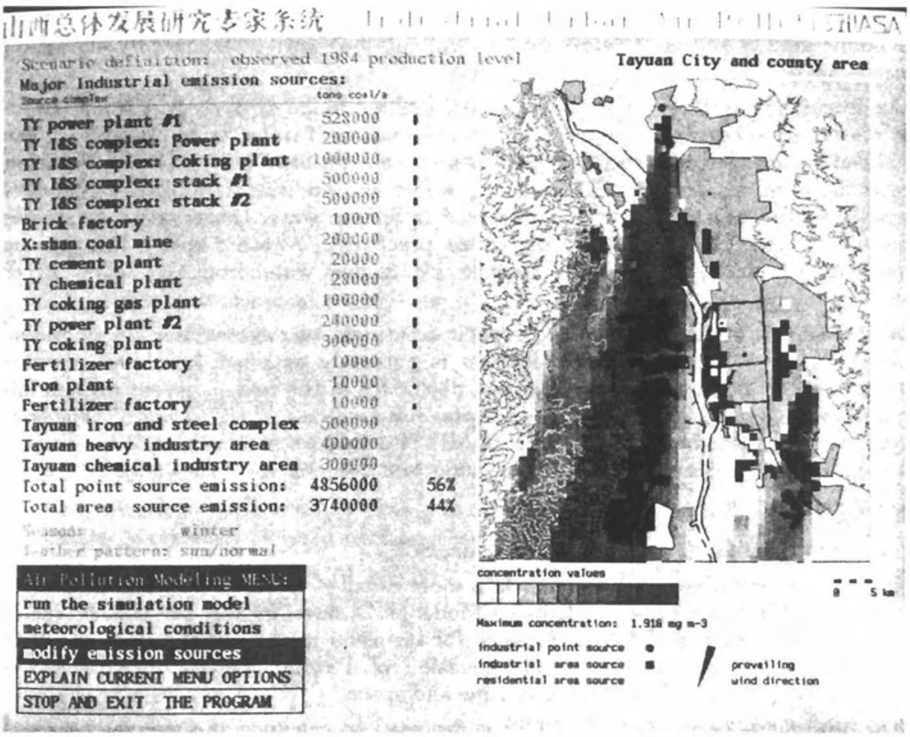

Figure 26: Regional air pollution model output for Taiyuan city

On the input side, a simple model of the cost-effectiveness of various pollution abatement technologies for emission reduction would be a logical policy-oriented complement of the atmospheric dispersion model.

In the current project phase neither a surface water pollution model nor a groundwater pollution model is foreseen. Severe surface and groundwater pollution problems however do exist in the province. Their explicit treatment, in particular in combination with a treatment of the more general waste management problem would be an important element in a more comprehensive environmental quality assessment. However, data requirements as well as the necessary computational effort are relatively large (e.g., Fedra, Diersch and Kaden, 1987), so that the inclusion of such models in the current project does not seem feasible.

Another open problem that would require specific treatment is soil erosion. Here an integration with the agricultural models foreseen for a next step would allow the evaluation of crop and technology alternatives as well as the role of afforestation in the control of soil erosion.

2.3.4 Population: Growth, Migration and Skills

Several of the above sectoral and cross-sectoral models draw on population data:

- domestic water use is based on per capita estimates;
- the models MAED, and PDA all require labor force data, including skill levels, acting as possible local or global constraints;
- the computation of per capita income, and per capita shares of other resources or services is a frequently used indicator at the macro-economic level.

Basic population data are found in the population data file, which is currently an integrated part of the towns data file (see 2.4.5).

However, given the time horizon of many planning problems of ten to thirty years and more, population dynamics will become an important factor to consider. A simple demographic model, that will estimate sex and age class distribution in time and space, will therefore be necessary for a next project phase. A subset of population models should be designed for the quantitative analysis of dynamic population processes. Input data required for these models are age and sex distribution of the population in a base year, and age-specific birth and death rates derived from demographic statistical data. The output includes the prospective population states (age and sex distribution, dependency ratios, etc.). The models should not only support the analysis of changing demographic patterns, including migration, but also the effects of changing per capita income, lifestyles, and government policies that relate to birth and death rates. This would specifically assist the analysis of population control policies.

The connection to the above-mentioned models requiring labor force data should be obvious. The labor force estimates, however, also include a qualitative component, i.e., education levels and job skills. This would require a component explicitly including the education and school system.

2.4 The Information System

The information system provides interactive access to the content of the system's databases. However, due to the system's object-oriented structure, information about a given object could also have been produced by means of some of the system's models. For the user, there is little difference.

For implementation and administrative purposes, we can differentiate between three different types of data and corresponding databases:

- static background information that is not going to be changed (e.g., historical data), or the databases proper; they also include graphical databases, containing coordinate files or Core graphics segments of e.g., maps, road networks, river basins, etc.;

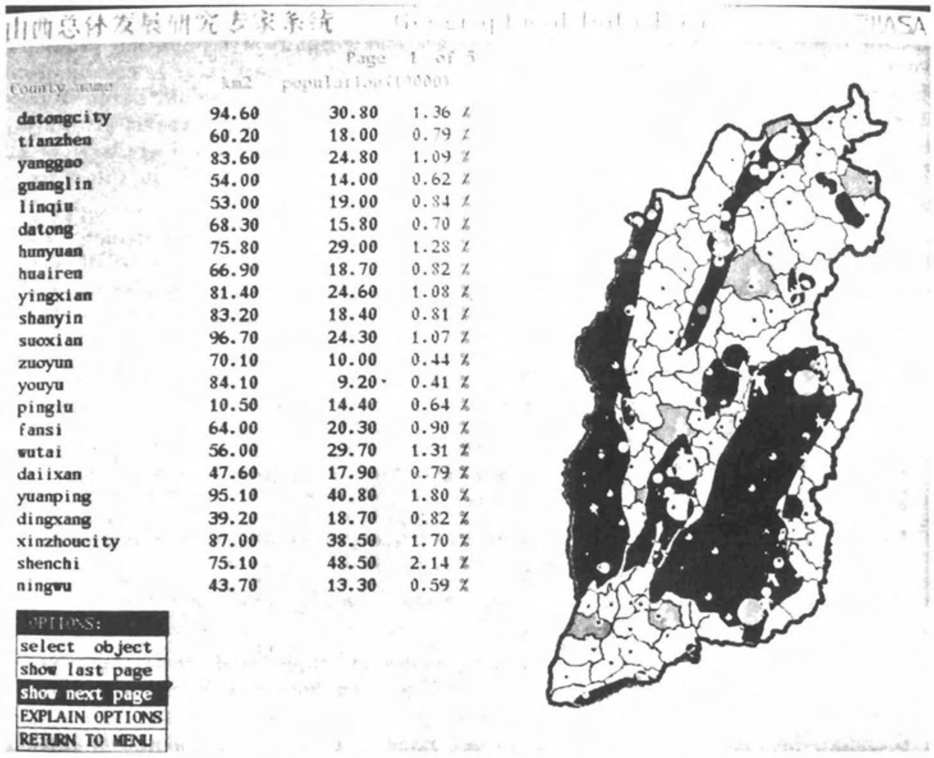

Figure 27: Population data from the regional database

- static background data (defaults) that the user can change in his working copy of the data (e.g., model coefficients describing technological or behavioral variables); while the defaults themselves cannot be changed, the user can edit a copy (read into memory) he is working with during a given session. Some of these changes can be stored permanently, representing a "scenario". Changes to the original default data can only be made by the system's administrator;
- dynamic or model generated data: these are results of using the system's components, and again, some of them can be stored permanently if the user so desires.

The basic data management philosophy uses numerous relationally organized data files (indexed random access for medium sized to larger ones); each of them is relatively small, and dedicated to a specific topic, e.g., counties, towns, industrial enterprises, technologies, river flow data, etc. This modular design is an important component of the rapid prototyping approach (see section 1.2), since it greatly simplifies the frequent redefinition and restructuring of data file contents during development. To avoid redundancies and overlaps, which would be necessary from any specific "user" (either the user or any of the system's models) perspective, the relational structure connects various files with the necessary indices or pointers. At the same time, structuring the individual files as (randomly accessible) arrays of records or (in C syntax) structures, only a small amount of information has to be loaded into the programs at any one time. Internal in-core representation and storage structure are very similar, allowing for simple access mechanisms.

Each of these data files is either

- a general data file, which is accessed by several modules (i.e., in addition to the display options of the information system, one or several models may use these data at least in part) with a standardized access and load routine through the relational indices and the indexed starting location of specific records in the files, or
- a model-specific data file, which then will be stored in whatever format the given model expects to find.

As a consequence, it is important to notice that all interaction with the databases is either through models and their specific input/output requirements, or through the menu-driven user interface. Since all possible queries are therefore known *a priori*, only a small but efficient set of data manipulation operations is required. Therefore, it becomes relatively easy to enforce the data independence often used as a measure of advanced database design:

> Ironically, the easiest way to support data independence, and to reduce demands on the user, is to provide very limited implementation options; yet this implicit corollary is rarely acknowledged (Pergamon Infotech Ltd., 1983).

2.4.1 Inter-regional Comparison at a Macro-economic Level

To compare different regions, or different development stages of the same region at a very high level of aggregation, a database of basic and macro-economic indicators for regional comparison is part of the system.

Figure 28: The comparative macro-economic database: selection of region or topic

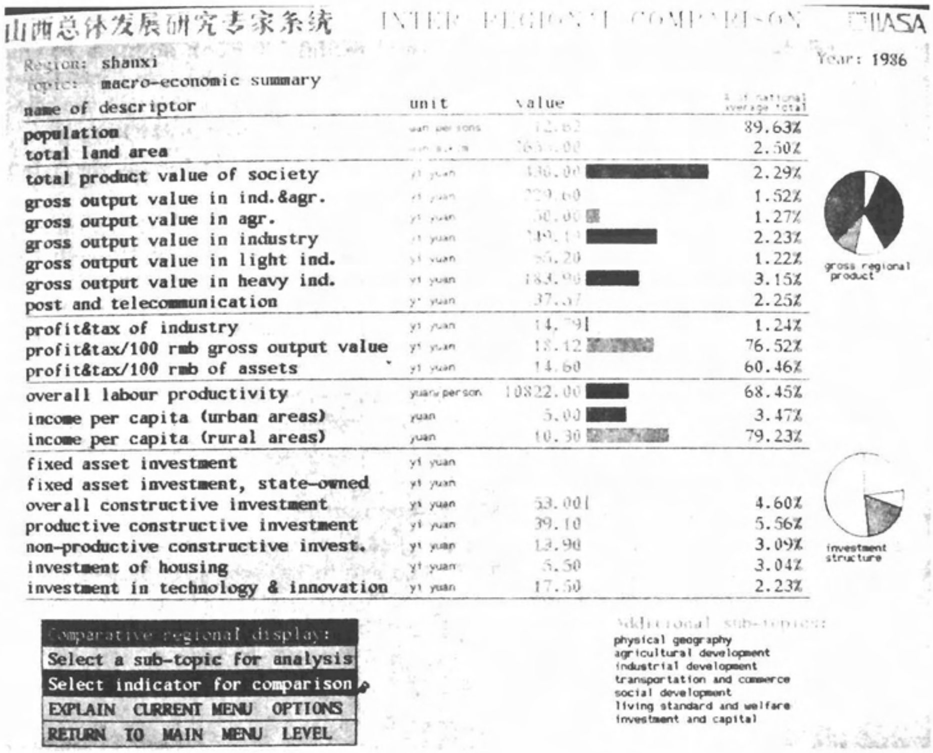

Figure 29: Summary display for a region

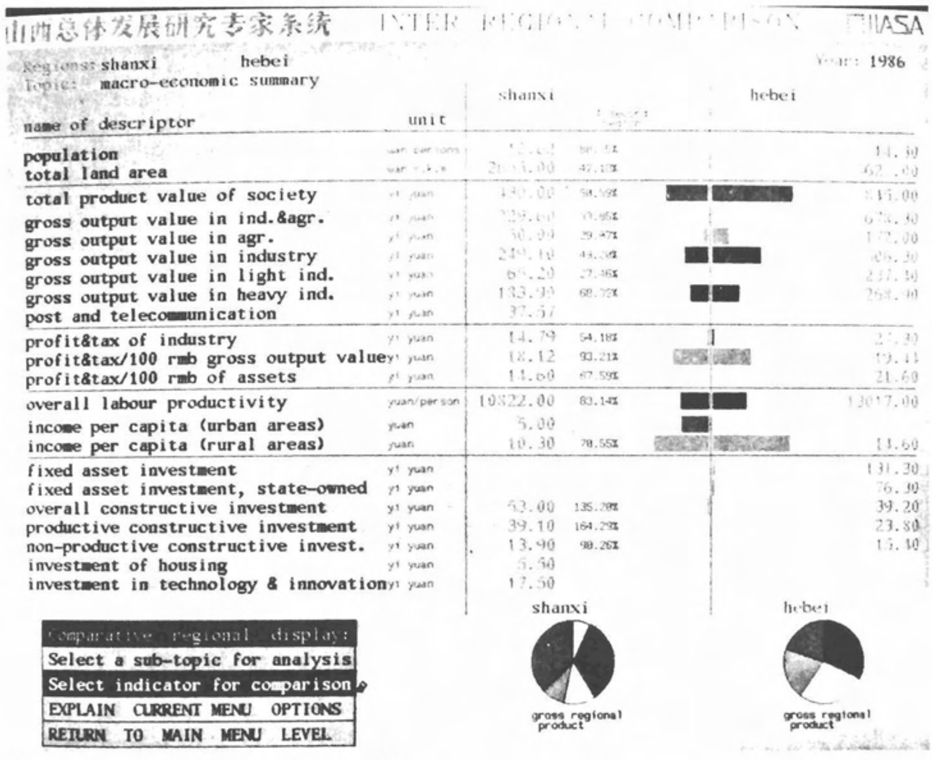

Figure 30: Comparison of two regions

Figure 31: Display/selection of indicators

Figure 32: Ranked list of provinces for an indicator

The interface to this database, which will hold data of Shanxi Province, several other Chinese provinces, and possibly also a few coal producing regions all over the world, also serves to display the results of scenario analysis, i.e., different possible states of Shanxi. In addition to the simple display of one region or two regions for direct comparison, several sorting and ranking options are available that will allow specific features of any one region (existing or hypothetical as resulting from model runs) to be put into perspective.

2.4.2 Coal Mines and Mineral Resources Database

The database will include information on individual mines, providing information such as name and location (linked to the towns and county databases), type of resource mined, available reserves, ownership, size (employees, current capacity), mining technology used, etc.

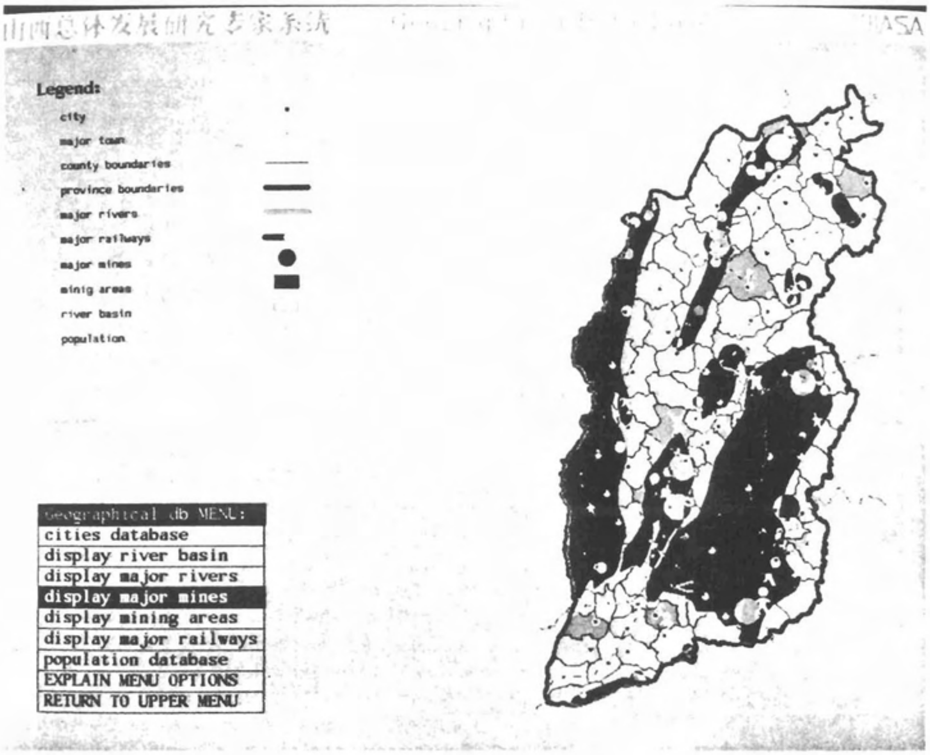

Figure 33: The coal and mineral resources database

This list-oriented information is supported by a map of the location, including an indication of the major mining areas.

2.4.3 Industrial Locations Database

The database summarizes information on individual industrial enterprises, including name, town, ownership, size/capacity, major products, technologies used, etc.

The entry may describe a specific enterprise (at a specific location), or a generic enterprise with multiple occurrences (usually small installations).

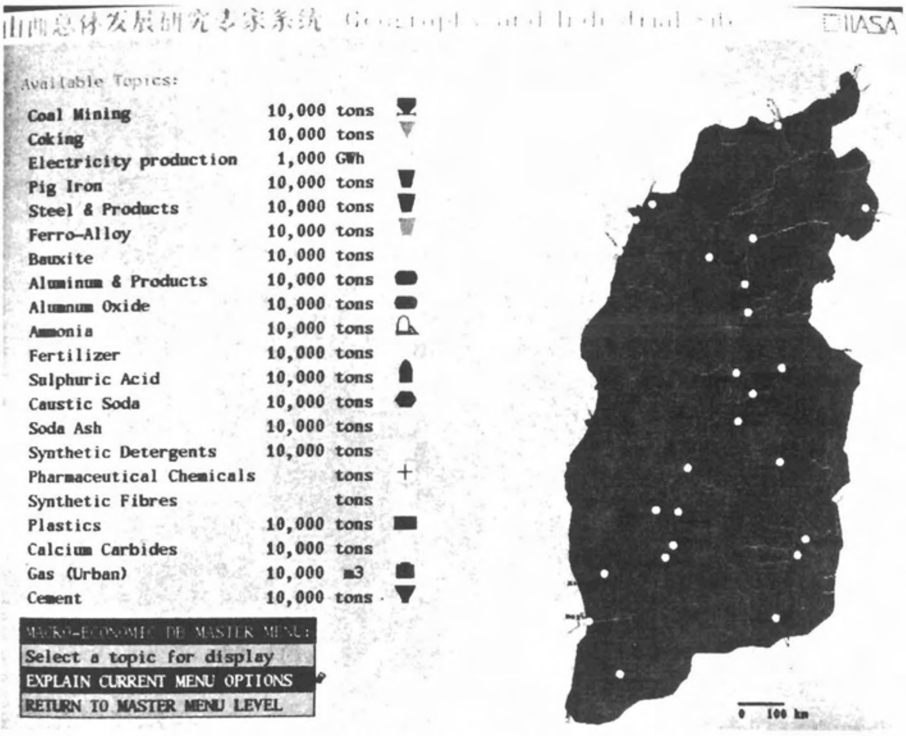

Figure 34: Industrial locations database: selecting an industry type

In addition to the above descriptors which are accessible through the interactive display interface, the database also contains numerous technology-specific coefficients used by the models MAED, PDA, and REPLACE.

2.4.4 Transportation Network Database

To allow the inclusion of transportation costs (and constraints) into the PDA model, a simple transportation network database has to be built. In its simplest implementation, the database will be structured as a matrix of unit costs and capacity limitations connecting any two industrial locations, demand nodes, or export targets in the system.

No specific transportation model that would require a more complex transportation network database (i.e., a system of nodes and arcs with numerous properties for each arc) is currently foreseen.

2.4.5 Geographical Background Data: Climate, Population, Water Resources

The geographical background data draw on several individual files, e.g., a database of towns, including population data, and counties, including some rudimentary land use information, that are connected to numerous other data files through the town or county ID (see above).

In addition, the module provides access to the flow data and the wind speed/direction data required for the water resources model and the water and air pollution model.

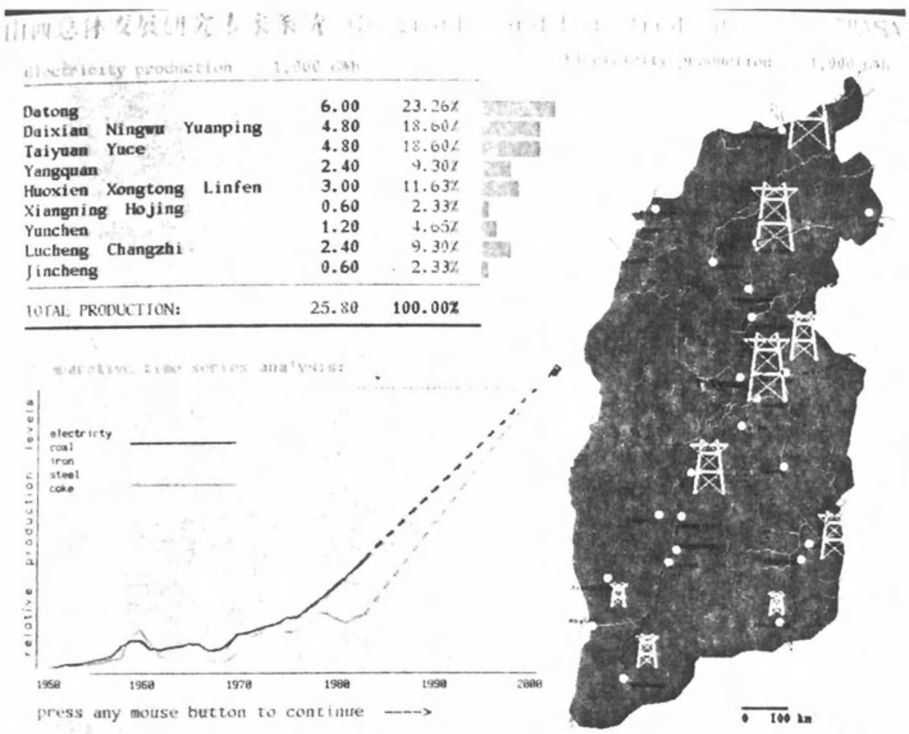

Figure 35: Industrial locations database: display of major sites

2.5 Integrated Decision Support

All the system's components discussed above provide information to decision makers in an attempt to improve the information basis for their decisions and thus support them. In addition to this concept of indirect decision support, we integrate a number of more direct and formal decision support tools into the above models and their post-processors.

Several of the above models are optimization models. They are, however, of a multi-criteria nature that does not allow for the automatic generation of a unique optimal solution. They require user interaction to formulate the trade-offs amongst objectives, and to assist in the formulation of these trade-offs is the primary purpose of the decision support modules provided.

2.5.1 The Multi-objective Approach: DIDASS

The models using explicit optimization in our system (one of the input/output model implementations and PDA) are all based on the DIDASS (Dynamic Interactive Decision Analysis and Support System) approach. Developed at IIASA largely in the SDS (Systems and Decision Sciences) program, it is based on methodology derived from the paradigm of satisficing decision making and the methodology of linear and nonlinear programming (Grauer et al., 1984).

The satisficing paradigm (March and Simon, 1958) assumes, that decision makers operate with target or aspiration levels, which may be modified with accumulating information, and make decisions that satisfy or come close to these targets. In other words, rather than explicitly trading off individual criteria or objectives or formulating a composite utility function *a priori*, the decision maker starts with a more or less clear but complex and possibly intuitive notion of what he wants, and then tries to get as close as possible.

A generalized method, proposed by Wierzbicki (1980a,b), combines the satisficing and aspiration level concepts with mathematical optimization. The approach concentrates on the construction of so-called achievement functions (a modified utility function) which, in simple terms, expresses how well the decision maker is on target, or the utility (or disutility) of attaining (or not attaining) given aspiration levels.

A detailed formal description is found in Grauer et al. (1984), and, in part, is given below for the discrete case where we have to select from a given set of alternatives rather than working with an optimization model capable of generating new alternatives.

2.5.2 Optimal Selection from Discrete Alternatives: DISCRET*)

In many cases, our system allows the user to generate a number of alternative scenarios, and analyze them by one or several models in the system. Each of these scenarios consists minimally of a set of control variables, and a set of performance variables. It is an extremely difficult and complicated task to compare and evaluate such a set of scenarios, rank them by several criteria representing conflicting objectives, eliminate less attractive alternatives and select one or a few interesting ones for further detailed analysis.

The problem mentioned above is a well known discrete, multiobjective decision problem, in which all feasible alternatives are explicitly listed in the finite set

$$x^0=\{x_1,x_2,\ldots,x_n\},$$

and the values of all criteria of each alternative are known and listed in the set

$$Q=\{f(x_1),f(x_2),\ldots,f(x_n)\}.$$

There are many tools which could be employed to solve this problem (e.g., Korhonen, 1985, Majchrzak, 1984). We have drawn on the method developed by Majchrzak (1985).

Usually, the procedure of problem solving is divided into two stages. The first stage is the selection of elements of a nondominated set from all the alternatives of set x^0. In the second stage, the "best" solution is identified as the decision maker's final solution to the problem under consideration, in accordance with his preferences, experience etc., as the basis for his decision.

In the discrete, multicriteria optimization module of the overall system, at the first stage of problem solving, the dominated approximation method is used to select the elements of the pareto set, because of its calculation efficiency and its ability to solve relatively large-scale problems. For instance, this method can be used to solve a problem with 15-20 criteria and more than a thousand alternatives, which is sufficient for processing the data arising from scenario analysis in the framework system.

In the second stage, an interactive procedure based on the reference point theory is employed to help the user to find his final solution. This approach combines the analytical power of the "hard" computer model with the qualitative assessments of the decision maker in the decision process. It makes the decision process more reasonable and closer to the human thinking process. In the following, the methodology used in these two stages will be described briefly.

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*) This section is based on the Reference Point Approach developed by Wierzbicki (1979, 1980) and draws on the DISCRET package developed by Majchrzak (1984, 1985); a first version was published in Zhao et al., (1985).

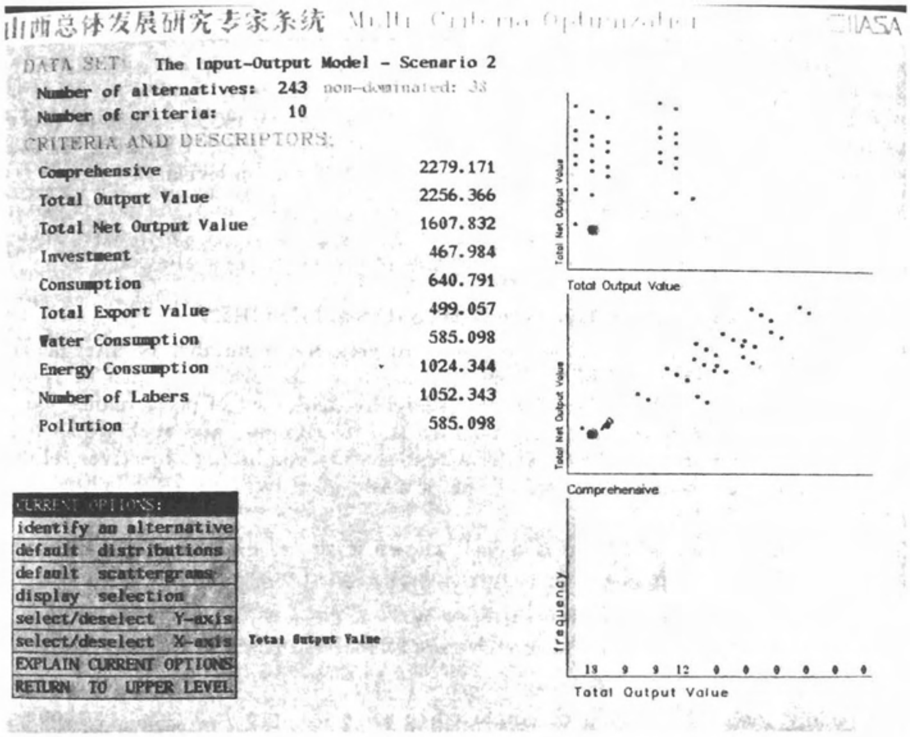

Figure 36: DISCRET application example: I/O model scenario comparison

Selection of the Nondominated Set of Alternatives

We may describe the problem considered as a minimizing (or maximizing or mixed) problem of m criteria with discrete values of criteria and a finite number of alternatives n.

Let x^0 be the set of alternative admissible decisions. For each of the elements of x^0, all criteria under consideration have been evaluated. Let Q be the criteria values set for all feasible discrete alternatives in the space of criteria F. Let a mapping f: $x^0 \rightarrow Q$ be given.

Then the problem can be formulated as follows:

$$\min f(x) \qquad x \in x^0$$

$$x^0 = \{x_1, x_2, \ldots, x_n\} \subset R^s$$

$$f(x) = \{f^1(x), f^2(x), \ldots, f^m(x)\}$$

$$f: x^0 \rightarrow Q$$

$$Q = \{f(x_1), f(x_2), \ldots, f(x_n)\} \subset F = R^m$$

The partial pre-ordering relation in space Q is implied by the positive cone $\Lambda = R_+{}^m$:

$$f_1, f_2 \in Q \quad f_1 < f_2 <==> f_1 \in f_2 - \Lambda$$

This means f_1 dominates f_2 in the sense of partial pre-ordering.

Element $f^* \in Q$ is nondominated in the set of feasible elements Q, if it is not dominated by any other feasible element. Let $N = N(Q) \subset Q$ denote the set of all nondominated elements in the criteria space and let $N_x = N(x^0) \subset x^0$ denote the set of the corresponding nondominated alternatives (decisions) in the decision space.

To solve this problem means to delete all the dominated alternatives - that is, alternatives for which a better one can be found in the sense of the natural partial ordering of the criteria - or to find the set N of nondominated elements and the corresponding set N_x of nondominated alternatives. Eventually, a final solution should be found from the set of nondominated alternatives.

The algorithm to select the nondominated set of alternatives is quite simple. The method implemented in our system is of the explicit enumeration type. It is called the method of dominated approximations and is based on the following notion.

Def. 1: Set A is called a dominated approximation of N if, and only if

$$N \subset A - \Lambda$$

i.e., if for each $f_i \in N$ there exists $f_j \in A$ such that $f_i < f_j$ in the sense of partial preordering induced by Λ .

Def. 2: The A_2 approximation dominates the A_1 approximation of the nondominated set N if, and only if

$$A_1 \subset A_2 + \Lambda$$

The method of dominated approximations generates a sequence of approximations A_k, k=0,1,2,...l such that

$$Q = A_0 \supset A_1 \supset \ldots \supset A_k \supset \ldots \supset A_l = N$$

given Q and Λ select N = N (Q), and assuming that all criteria are to be minimized. Then the procedure of problem solving can be described as follows.

Step 0: let $A_0 = Q$, $N = \Phi$, $K = 0$

Step 1: If $A_k \setminus N = \Phi$ then stop,

else choose any index $i \in I=\{1,2, \ldots ,m\}$ and find $f^* \in Q$ such that

$$f^*_i = \min f^i$$

set $N = N \cup \{ f^* \}$ and go to step 2.

Step 2: Create the new approximation A_{k+1} by f^*

$$A_{k+1} = \{ A_{k+1} \setminus N \} \ \{(f^* + \Lambda) \cap (A_k \setminus N)\} \cup N$$

set K = K + 1 and go to step 1.

As a result of the above procedure the nondominated set N of alternatives is found when the stopping condition $A_k \setminus N = \Phi$ is satisfied.

The Reference Point Approach

After the system eliminates, by the method mentioned above, all the dominated alternatives, the set of remaining nondominated alternatives is usually large and its elements are incomparable in the sense of natural partial ordering. To choose from among them, additional information must be obtained from the decision maker. The main problem of multicriteria optimization is how and in what form this additional information may be obtained, such that it satisfactorily reflects the decision maker's preferences, experience and other subjective factors.

There are many methods for obtaining that additional information and to then find the final or the "best" solution according to the decision maker's preference. The most common method is the weighting coefficients method, which plays a central role in the basic classical theory of multiobjective decision analysis. It represents a traditional method of multicriteria optimization.

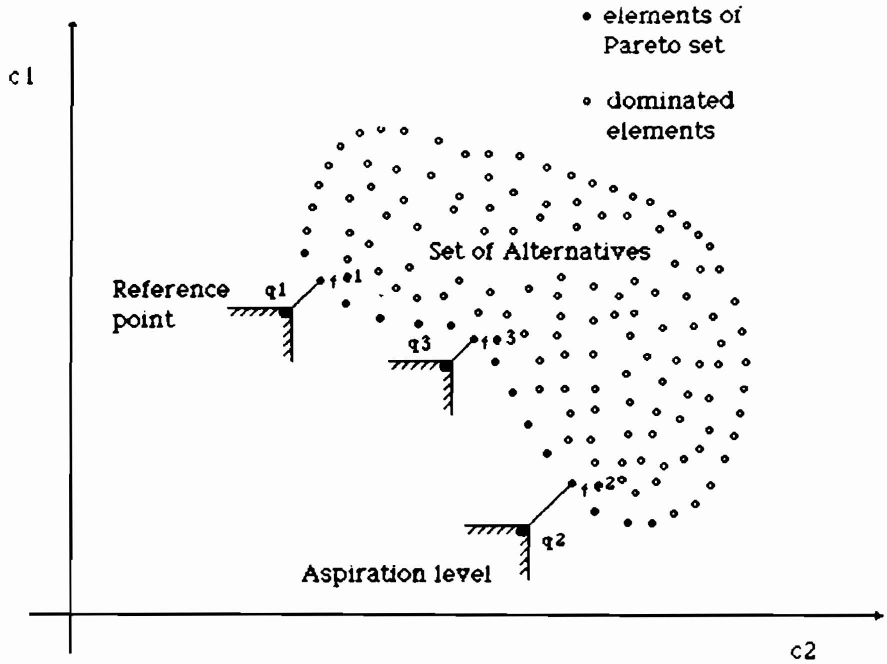

Figure 37: The interactive procedure of the reference point approach

However, certain difficulties often arise when applying the weighting coefficients method to real-world decision processes: Decision makers usually do not know how to specify their preferences in terms of weighting coefficients. Before running a multiobjective model, some of them do not even have an idea about their weighting coefficients.

Most of them are not willing to take part in psychometric experiments in order to learn about their own preferences. Sometimes the decision maker has variable preferences as time, and the information available to him changes. The applicability of the weighting coefficients method to real world problems is severely restricted by these factors.

It is obvious that decision makers need an alternative approach for multicriteria optimization problems. Since 1980 many versions of software tools based on reference point theory have been developed at IIASA, such as DIDASS/N, DIDASS/L, MM, MZ, Micro DIDASS etc. These tools can deal with nonlinear problems, linear problems, dynamic trajectory problems, and committee decision problems. Recently many application experiments have been reported by numerous scientific papers and reports (e.g., Grauer, et al. 1982, Kaden & Kreglewski, 1986, Kaden, et al. 1986 and Kaden, 1986).

The reference point approach is based on the hypothesis that in everyday decisions individuals think rather in terms of goals and aspiration levels than in terms of weighting coefficients or maximizing utility. This hypothesis is quite close to the real-world decision-making process.

Using the reference point approach, the decision maker works with a computer interactively. There are two distinct phases in the approach:

In the first stage, the exploratory stage, the decision maker may acquire information about the range and the frequency distribution of the alternatives thus giving him an overview of the problem to be solved. The decision maker may also set some bounds for the criteria values of the alternatives set to focus his interests on a certain area.

In the second stage, the search stage, at first the decision maker is required to specify his preferences in terms of a reference point in the criteria space. The values of the criteria represented by the reference point in the criteria space are the values the decision maker wants to obtain, i.e., the goal of the decision maker, which reflects his experience and preferences.

Next, the system identifies an efficient point, which is one of the alternatives closest to the reference point. The efficient point is the "best" solution of the problem under the constraints of the model and with respect to the reference point specified by the decision maker.

If the decision maker is satisfied by this solution, he can take it as a basis for his final decision. If the decision maker is not satisfied by this solution, he may modify his goal, i.e., change the reference point or change the constraints, i.e., change the bounds he had set before, or both, or create some additional alternatives in order to obtain a new efficient point. In the case of continuous variables problems, i.e., the problems described by continuous models (linear or nonlinear programming models or dynamic control models), the reference point method is able to generate new alternatives on running the model again.

The Mathematical Description of the Approach

The approach currently implemented in the framework system is as follows: for the sake of computability, it is necessary to define an achievement scalarizing function which transforms the multiobjective optimization problem into a single objective optimization problem. After having specified his preferences in terms of a reference point, which need not be attainable, the decision maker obtains an efficient point which is the nondominated point nearest to the reference point in the sense of the scalarizing function.

In our data post-processor the Euclidean-norm scalarizing function is used. Let q be the reference point specified by the user. Then assuming that the optimization problem under consideration is a minimization problem for all criteria (for maximizing problems one may easily transform it into a minimizing problem by changing the sign of the related criteria), the following scalarizing function is minimized:

$$S(f\text{-}q) = - ||(f\text{-}q)||^2 + \rho \, ||(f\text{-}q)_+||^2$$

where $(f\text{-}q)_+$ denotes the vector with components $\max(0,f\text{-}q)$, $||.||$ denotes the Euclidean norm and $\rho > 1$ is a penalty scalarizing coefficient.

The solution f^e for minimizing the scalarizing function S is an efficient point of the problem with respect to the specified reference point.

If necessary, this procedure can be repeated until the decision maker is satisfied by an efficient point.

Figure 37 shows that after changing the reference point twice, finally the decision maker obtains a satisfactory efficient point f^{e3} corresponding to reference point q^3.

2.6 The User Interface

The user interface is one of the cornerstones of this system. It is the user interface that provides the ultimate translation of the machine's representation of information into symbols intelligible to humans.

The basic design guidelines for the user interface are the following:

- it is strictly menu-driven, the primary user input device is a three-button "mouse" for option selection;
- it is largely symbolic and minimizes numerical and language features;
- it is based on the extensive use of high-resolution color graphics.

The system described in this report is implemented on a high-resolution color graphics workstation, offering a resolution of 1 million pixels and a color palette of 256 simultaneous colors. This allows us to base the entire interface on graphics elements on the bit-mapped screen; no "terminal" style interaction with scrolling alphanumerical text is used.

The approach offers several important advantages: while on the one hand we can allow for a highly dynamic display, e.g., for the output of dynamic models, or fast paging of sub-windows, the overall appearance of the screen is static. Everything on display has a fixed position and remains wherever it was displayed in the first place. This allows for easy orientation and the quick recognition of patterns and layouts, and does not force the user to scan the screen for specific items repeatedly as they change their position during scrolling.

Standardized screen layout (e.g., the menus are always in the lower left corner, prompt messages appear on the bottom lines, etc.) eases learning, supports recognition, and provides an optical context that makes it easy to identify specific items of interest on a well-structured screen. Clearly, the use of colors can support the structuring of a screen's information context considerably.

Another important concept is that of immediate feedback. Whatever the user does, immediate feedback must follow every one of his actions. This includes dynamic status indicators, e.g., highlighting the menu option that is currently identified by the mouse pointer before it is actually selected by clicking the appropriate button, or informing the user in very short intervals what the system is currently doing, acknowledging any user input, and providing immediate diagnostic feedback in case of infeasible input.

A third concept is that of hierarchical aggregation of information contents. The bandwidth of the high-resolution color screen is very high, and the user can easily get overwhelmed by the amount of information displayed. Thus, every screen by default only provides a manageable subset of the information available at the highest possible level of aggregation. The user is then invited, by the appropriate menu options, to descend the hierarchical information structure and display more and more detailed information. However, the context of the original top-level and intermediate levels is preserved by keeping as much of the higher-level information current as possible and by keeping the layout of the display constant as much as possible.

3. Systems Integration: The Expert Systems Approach

The project designs, develops and implements an *integrated set of software tools*, building on several existing models and computer-assisted procedures, as well as on new and emerging concepts and tools of AI.

This integrated set of software tools is designed for a broad group of users with diverse, including non-technical, backgrounds. Its primary purpose is to provide easy access and allow efficient use of methods of analysis and information management which are normally restricted to a small group of technical experts. By combining numerical and symbolic methods, a synthesis of rigorous mathematical treatment and human expertise and judgement can be obtained in a new generation of hybrid information and decision support systems.

The decision support system described here is based on *information management* and *model-based decision support*. It envisions experts as its users, as well as decision and policy makers, and in fact, the computer is seen as a mediator and translator between expert and decision maker, between science and policy. The computer is thus not only a vehicle for analysis, but even more importantly, a vehicle for communication, learning, and experimentation.

The three basic, interwoven elements, are

- to supply *factual information, based on existing data*, statistics, and scientific evidence,
- to assist in *designing alternatives* and to assess the likely consequences of such new plans or policy options, and
- to assist in a systematic *multi-criteria evaluation and comparison* of the alternatives generated and studied.

The system is characterized by methodological pluralism. The individual components of the system are based on quite different conceptualizations, levels of aggregation, and methods of analysis: Numerical simulation, mathematical programming, symbolic simulation, interactive database access, and rule- and inference-based information retrieval all of which must be integrated into one coherent system.

To integrate these different sources of information, make them compatible, and present a coherent and immediately accessible picture to the user requires an advanced framework and user interface.

One basic concept of our design is the object-oriented structure, that allows multiple sources of information to either alternatively or complementarily describe an *object* as seen by the user. Which source of information, which concept or which level of detail will be used depends on the context (i.e., the history of the interactive session), and the specifics of the query, just as in human communication where an expert can very well integrate different sources of information and present them together in a smooth and natural style appropriate for a given audience.

A second set of important elements of integration are message passing, a blackboard system and a mailbox system. The multitude of quite different system's modules must not only communicate with the user, they must communicate with each other. The result of invoking any of the system's objects is not only information that is relevant for the user. The same information may of course also be relevant for any consequently invoked objects, defining a context and history for each new task.

Keeping track of all these messages, definitions, and results, and structuring the system's behavior according to "*what has been said before and is known or asserted at any given point in time*" is a major task. But it is exactly this context and history awareness that is responsible, to a considerable degree, for the apparent intelligence of a system. The mechanisms employed range from direct message passing between tasks to the generation of receiver-specific pass files and their deposition into mailboxes, as well as a more flexible and sender-oriented to-whom-it-may-concern blackboard system.

3.1 Hybrid Systems: Embedded AI Technology

Application and problem-oriented rather than methodology-oriented systems are most often *hybrid systems*, where elements of AI technology are combined with more classical techniques of information processing and approaches of operations research and systems analysis. Here traditional numerical data processing is supplemented by symbolic elements, rules, and heuristics in the various forms of knowledge representation.

There are numerous applications where the addition of a quite small amount of "knowledge" in the above sense, e.g., to an existing simulation model, may considerably extend its power and usefulness and at the same time make it much easier to use. Expert systems are not necessarily purely knowledge driven, relying on huge knowledge bases of thousands of rules. Applications containing only small knowledge bases of at best a few dozen to a hundred rules can dramatically extend the scope of standard computer applications in terms of application domains as well as in terms of an enlarged non-technical user community.

3.2 Levels of Knowledge Representation

Due to the diverse nature of the information required, we have chosen a hybrid approach to data/knowledge representation, combining traditional database structure and management concepts (e.g., relational databases) with knowledge representation paradigms developed in the field of AI and implemented in AI languages such as LISP or PROLOG. While most of the "hard" and often numerical or at least fixed-format data are organized in the form of special-purpose data files with a relational concept of interfile connections (see section 2.4), the knowledge bases again use a hybrid representation approach.

Hybrid Knowledge Representation implies that within our information system, multiple representation paradigms are integrated. A knowledge base might therefore consist of term definitions represented as frames, object relationships represented in predicate calculus, and decision heuristics represented in production rules.

Predicate Calculus is appealing because of its general expressive power and well-defined semantics. Formally, a predicate is a statement about an object:

((property_name) (object) (property_value))

A predicate is applied to a specific number of arguments, and has the value of either TRUE or FALSE when applied to specific objects as arguments. In addition to predicates and arguments, Predicate Calculus supplies *connectives* and *quantifiers*. Examples for connectives are AND, OR, IMPLIES. Quantifiers are FORALL and EXISTS, that add some inferential power to predicate calculus. However, for our purpose of building up a representation structure for more complex statements about objects, predicate calculus representation becomes very complicated and clumsy. We have therefore integrated it in our system only to represent internal facts used by the inference module.

PROLOG example:

```
coal_production(datong,50000KTons/Year).
coal_production(yuanping,24000KTons/Year).
coal_production(taiyuan,35000KTons/Year).
```

LISP example:

```
coal-production -->
((datong 50000KTons/Year)
 (yuanping 24000KTons/Year)
 (taiyuan 35000KTons/Year))
```

In *object-oriented representation* or *frame-based knowledge representation*, the representational objects or *frames* allow descriptions of some complexity (Minsky, 1975). Objects or classes of objects are represented by *frames* which form a hierarchy in which each object is a member of a class and each class is a member of a superclass (except the top-level classes). A frame consists of *slots* which contain information about the attributes of the objects or the class of objects it represents, a reference to its superclass and references to its members and/or instantiations, if it is a frame that represents a class. Frames are defined as specializations of more general frames, individual objects are represented by *instantiations* of more general frames, and the resulting connections between frames form *taxonomies*. A class has attributes of its own, as well as attributes of its members. An object *inherits* the member attributes of the class of which it is a member. The inheritance of attributes is a powerful tool in the partial description of objects, typical for the ill-defined and data-poor situations the system has to deal with.

A LISP frame example (Flavor):

Generic Frame:

```
(defflavor Mining-Region
  ;;; slots with default values
   ((local-coal-demand Y1)
    (existing-big-mines Y2)
    (existing-medium-mines Y3)
    (existing-small-mines Y4))
  ;;; component flavors, i.e. superclasses for property inheritance
   (Region)
  ;;; options to enable slots to be accessed and set via message passing
 :settable-instance-variables
)
```

Y1,Y2,Y3,Y4 ... default values for the slots

Instance:

```
(setf datong (make-instance Mining-Region :existing-big-mines Z1))
```

Z1 ... local slot value which overrides default (Y2)

A PROLOG frame example:

Generic Frame:

```
mining_region ===> slots local_coal_demand:=Y1,
                   existing_big_mines:=Y2,
                    existing_medium_mines:=Y3,
                   existing_small_mines:=Y4.

mining_region ===> is_a simulation_object.
```

Instance:

```
make_object(datong,mining_region,[Y1,Z1,Y3,Y4]).
```

A third major paradigm of knowledge representation is *production rules (IF - THEN decision rules)*: they are related to predicate calculus. They consist of rules, or *condition-action pairs*: "if this conditions occurs, then do this action". They can easily be understood, but have sufficient expressive power for domain-dependent inference and the description of behavior.

For example a production rule which changes the project priority for MINE-PROJECT depending on the amount of coal resources, an investment rate, a return period for the investment, and finally the environmental conditions characteristic for the project site can be expressed as follows in LISP:

```
(Decision-Rule
 (IF (AND
     (greater (send MINE-PROJECT :amount-of-resources) X1-Tons))
     (greater (send MINE-PROJECT :investment-rate) X2-Tons/Year))
     (less (send MINE-PROJECT :return-period) X3-Years))
     (same (send MINE-PROJECT :environment-conditions) 'acceptable))))
 (THEN (increase-project-priority MINE-PROJECT)))
```

and in PROLOG:

```
increase_project_priority(MINE_PROJECT) :-
     greater(amount_of_investment(MINE_PROJECT),X1_Tons),
     greater(investment_rate(MINE_PROJECT),X2_Tons/Year),
     less(return_period(MINE_PROJECT),X3_Years),
     same(environment_conditions(MINE_PROJECT),acceptable).
```

Finally, it should be mentioned that within the above hybrid knowledge representation framework, complex numerical models are yet another special form of knowledge representation. They can be viewed as composite sets of production rules, usually expressed in algorithmic form.

3.3 An Intelligent Man–Machine System for Interactive Systems Analysis

The development planning information and decision support system introduced and described above is a computer-based tool for interactive systems analysis. The object of the study, namely the multitude of interrelated development problems of a region, is very complicated and complex, and one cannot expect a concise *a priori* problem formulation. Problem formulation is a major task of the system itself, i.e., assisting the user in the incremental definition and redefinition of a certain problem situation on the basis of the information supplied by the system.

This tightly interactive procedure requires an intelligent and very responsive man–machine system, where, instead of learning to fly an aircraft or run a nuclear power plant in a simulator, the user experiments with planning a region's development.

Because of the immense complexity of a regional system with all its physical, technological, economic, and socio-political components and aspects, the role of the user and his integration into the system are most important. To allow this tight integration, however, the system must provide the necessary intelligence to be acceptable to the non-technical user. While people interacting with computers routinely are usually prepared to accept a program's rigid stupidity, a novice user, and a high-level decision maker in particular, will be much less forgiving.

User friendliness simply means that the user is freed from onerous tasks such as memorizing a special language of interaction, the translation of the computer's response to his own problem representation formats, and having to worry about the computer rather than his problem. To assist the user as much as possible, we believe that a strictly menu-driven system is preferable to a command-driven design in view of the expected largely non-technical user community (see section 1.6). However, we also consider a flexible style of interaction essential. An example would be the possibility to set a given magnitude either in absolute or relative terms, using either graphical symbols or language or numbers.

To the user, the system should look like a very resourceful and efficient human expert, or a group of experts. Structure and language, i.e., the symbols and relationships of the conversational dialog should be natural and directly meaningful. The primary purpose of the system is to provide a structuring framework for learning about a problem. This includes supplying the available background information, tools for *what if* ... questions that permit an assessment of the consequences of specific actions or composite policies on the system's behavior, and assistance in structuring, sorting, ranking, and organizing results for comparative evaluation.

All these functions, however, should be task- or problem-specific, and available through the respective context-dependent menus. What the system suggests as options must be what the user would naturally want to do, it must make sense in the given context and the given history of a working session with the system.

The major features that we hope will help to make the system "intelligent" are:

- the multiple and flexible problem definition and representation;
- the mixture of quantitative and qualitative representation and reasoning;
- a rich set of symbols and styles of presenting information;
- a context- and history-dependent dialog, based on a memory of previous actions and extensive internal communication;
- a problem-oriented structure that provides custom-designed rather than standardized tools and interface components.

Finally, it should be emphasized that the systems concepts are to a high degree experimental, that they must be subjected to practical tests and numerous adaptive revisions and improvements. Flexibility to adapt to changing user requirements, which we expect to be formulated more precisely on the basis of consecutive prototypes, and to a changing application environment, institutional structures, and user experience, is therefore a major requirement for successful implementation.

4. Possible Extensions and Further Development

4.1 A Structure for Object-oriented Coupling: KIM*)

Rapid prototyping has always had high priority in AI, on the understanding that the structure used for a prototype which can be built in the shortest possible time is flexible enough (extendable, easy-to-modify, etc.) to let all appealing extensions be added later without having to change the basic structure of the prototype. This basic idea led to the development of knowledge representation and techniques such as *production rules, semantic networks, object-oriented programming (frames)* and *blackboard architecture.*

All these techniques are now being used successfully as structures for pure AI systems (i.e., systems relying totally on symbolic computation) in order to achieve rapid prototyping during the first development phase. Two of these techniques - object-oriented programming and blackboard architecture - are also used widely as basic structures in coupled systems (i.e., systems which combine symbolic and numerical computation).

For coupled systems such as in this study however, *rapid prototyping* means a bit more than for pure AI systems. In the field of coupled systems one of the most appealing approaches is to achieve *deep coupling* of numerical and symbolic computing, i.e., to utilize extensive knowledge of each module representing the module's function, inputs, outputs, usage constraints and the like and by using it directly in knowledge-based system components during problem solving. This permits the system to be applied to a wider range of problems, makes it more robust and in all act more "intelligent" (Kitzmiller and Kowalik, 1986).

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*) Section based on the paper A Structure for the Incremental Construction of Coupled Systems: A Bridge between Shallow and Deep Coupling by Lothar Winkelbauer presented at the workshop on Coupling Symbolic and Numeric Computing, July 20-23, 1987, Seattle, Washington.

Although this is widely accepted, most of the current systems which claim to be coupled systems are *shallow coupled* ones, i.e., the software modules to be coupled are treated as "black boxes" and only a little knowledge of the modules involved is incorporated in the knowledge-based system component which actually does the coupling. Sometimes the shallow coupling approach is not only acceptable but preferable (e.g., when the modules are coupled to perform signal processing), but most of the time it is chosen because it is faster to implement and shows the beneficial effects of the coupling (usually an increase in performance) earlier.

Even when the techniques well suited to rapid prototyping in pure AI systems are used, the structures developed so far for shallow coupled systems do not allow such a system to be extended later to a deep coupled one. This means that the objective of rapid prototyping can not be fulfilled by the use of these structures.

In the following sections, a structure for rapid prototyping in coupled systems is presented, which allows a smooth upgrade of a rapidly developed shallow coupled system to an intelligent deep coupled system. The proposed structure is flexible, easy to extend and can be incrementally implemented, thus enabling true rapid prototyping, efficiency in performance and development of problem-oriented systems.

The Design Structure

In general, the integrated knowledge-based system the proposed structure is dedicated to consists of several more-or-less independent (e.g., numerical and symbolic simulation and optimization) software modules which have to be applied within a common context in order to be able to fulfill the user's requests. Further, the current prototype is based on a rigid, menu-based integration of the individual components. We are at present investigating a more flexible LISP-based structure.

To enable coordination of these modules a Knowledge-based Integration Manager (KIM) has been conceived, based upon an object-oriented approach (Tompkins, 1986) combined with blackboard architecture (Hayes-Roth, 1983). KIM not only coordinates the software modules of the system, but also conducts the dialog with the user via an I/O device (Figure 38) i.e., a color graphics screen and a mouse-like input device.

The Components of KIM

KIM itself consists of two heterarchically organized categories of frames, a Blackboard and a Scheduler (Figure 39). One category of frames (the *Module Frames*) represents the characteristics of the modules to be coupled (one instantiated frame for each module) to allow for an efficient selection and sequencing of the modules. The other category of frames (the *Transformation Frames*) enables communication between the numerically-oriented modules and between symbolically-oriented and numerically-oriented software modules by specifying message transformation conventions for specific message types. The communication itself is handled via *Request Messages* and *Result Messages* which are sent from all Module Frames to the *Blackboard*. The *Scheduler* reads the messages from the Blackboard and either hands it over to the user (i.e., displays it on the screen) or sends it to a specific frame or frame class - modified or unchanged, depending on the Scheduler's internal knowledge, and the interaction with the user, which is also handled by the Scheduler.

The Module Frames

are organized in two levels of frame classes:

- on the first level, with respect to the types of tasks (e.g., simulation, optimization, etc.) the modules are able to fulfill;

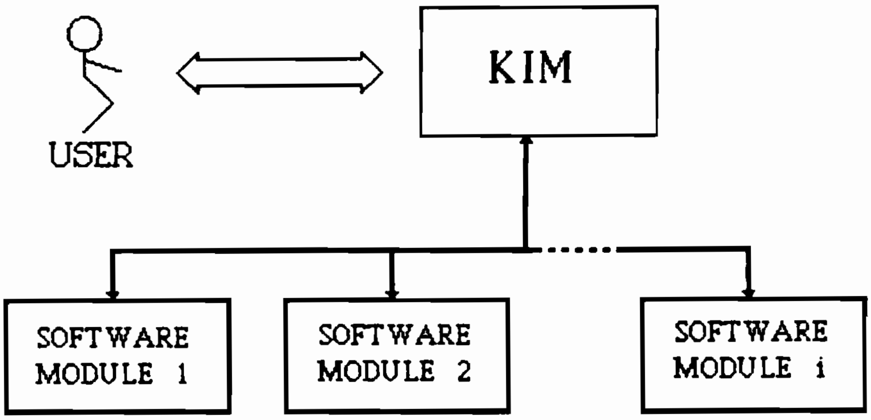

Figure 38: Overall system structure

- on the second level, with respect to the module types which emerge from the combination of software module characteristics inherited from the first level of frame classes with the facts and methods inherited from the message transformation types, inherited from the Transformation frame classes (see below).

They

- state whether a specific request can be fulfilled by the software module which the frame represents on an abstract level;
- provide defaults and methods to set up well-suited and valid startup conditions for the activation of the software module;
- activate the software module;
- should be able to control the execution of the module (depending on the availability of multiple processors i.e., parallel processing);
- check and interpret the results of the module execution;
- write the Result Message on the Blackboard;
- store Request and Result Messages (positive as well as negative) in the message records of the frame so as to avoid redundant activation of the software module later on.

The Transformation Frames

For all types of Request and Result Messages which are to be sent from a numeric to a symbolic module (or vice versa), there is a Transformation Frame which comprises methods and facts of how values contained in the message have to be transformed so that they can be interpreted by the target Module Frame.

The Blackboard

is a stack of Request and Result Messages, separated into *accomplished* and *active* messages, to which all instantiated Module Frames can write and from which the Scheduler can read. The active messages are the ones which are required to perform a task which

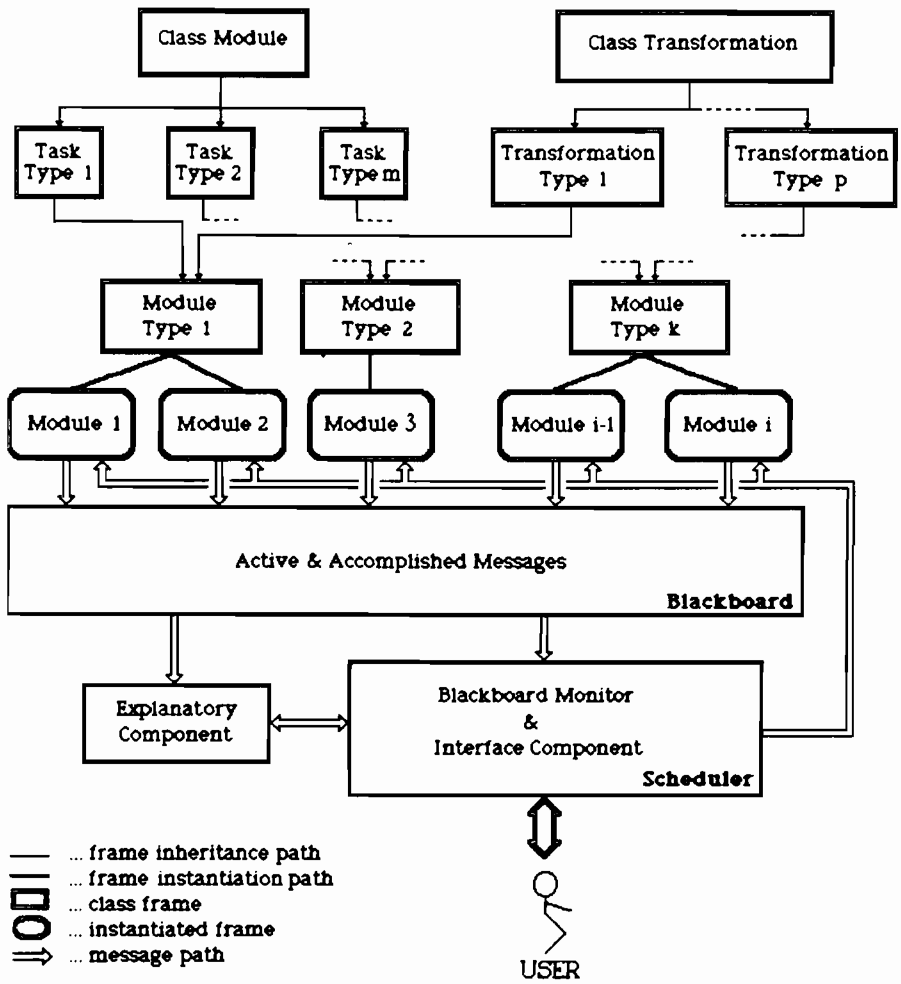

Figure 39: Components of KIM

has not been completed. When they are no longer needed for the completion of the task they are stored as accomplished messages to enable an *a posteriori* explanation of what and how KIM performed.

The Scheduler

consists of a *blackboard monitor* to

- read messages from the Blackboard;
- compose and modify messages;
- send messages to specific Module Frames and frame classes;

and a user *interface component* to

- conduct user interaction (preferably by making use of graphics packages, menus etc.)

The Explanatory Component

To enable KIM to explain its actions (on what has been done and how) a module which interprets the accomplished messages stored on the Blackboard, on user request via the user interface component of the Scheduler, can be implemented. Although this module is not necessarily required to get KIM to do its job, it is very important in terms of user acceptance and systems transparency.

Message Passing

When a coupled system directed by KIM starts up the initial Request Message (e.g., "display startup screen") is read by the Scheduler from the Blackboard. Triggered by that, the Scheduler lets the user specify his problem. The Scheduler then transforms this problem specification into a Request Message and sends this message – in keeping with the task it is dedicated to – to a specific Module Frame or frame class. This activates the target frame. It first checks if it, or the software module it represents on an abstract level, can fulfill the requested task. If this is not possible, a negative Result Message is sent to the Blackboard. When there is another module available which could be considered as capable of fulfilling the task, the Scheduler formulates a new Request Message and sends it to the respective Module Frame. If there is no other module which could take over, the negative outcome is presented to the user and he is asked to respecify his problem.

If the Module Frame deduces that it is possible to fulfill the task for its software module, then a Request Message asking for the user's confirmation or update of the default starting conditions is sent. The Scheduler then presents this request together with the default conditions (which are also contained in the message) to the user and transforms the user's reaction (approval of the default or update of one or more starting conditions) into a Request Message which is then sent to the specific Module Frame again. The frame checks the conditions and sends a "change this or that condition" Request Message to the user (via Blackboard and Scheduler) until all conditions are valid. Then the frame looks up its records, to check if there has already been a similar request. If this is the case, then it simply recalls the correlated Result Message from the records and sends it to the Blackboard. If the request is a new one, then the software module (a symbolic or numerical software package) whose characteristics the Module Frame represents is started to compute the results. These results are then – after the module execution has terminated – transformed into a Result Message which is written on the Blackboard and then presented to the user.

If the task can not be fulfilled by a single software module, then the Module Frame which receives such a request first sends out the Request Messages for that part of the task it can not accomplish so that the respective Module Frames are activated via Blackboard and Scheduler. These messages are not presented to the user, i.e., for the user there is no difference if a task is fulfilled by one or more software modules, or if only the records of the Module Frames have to be searched.

Utilizing the KIM Approach

The First Prototype

To facilitate parallel development and testing of the software modules to be integrated, each module is responsible for the user interaction internal to the module (i.e., the interaction which is needed after the module has been activated). The Module Frames comprise only very little knowledge about their "own" software modules and are responsible for the setup of valid (default) startup conditions only. Most of the knowledge on how the modules interact is implanted in the Scheduler*). Only a few necessary Transformation Frames exist and the Explanatory Component is not implemented.

Stabilizing the Shallow Coupling

After the first successful run of the prototype it is necessary to decentralize the coordination of the module interaction, i.e., to remove a lot of the procedural representation of the coordination knowledge from the Scheduler and to install it as methods of the Module Frames. The number of Transformation Frames is increased by improving the coverage of messages and the accuracy of the transformations. A first rudimentary Explanatory Component is implemented and is used, at least in the beginning, for debugging KIM rather than for serving a user. The user interface is centralized, step by step, in the Scheduler.

En Route to Deep Coupling

Whenever a new module is added to the system an increase in knowledge about the modules correlated to the new module is necessary in the respective Module Frames to enable KIM to determine in what way the modules differ. This leads, stepwise, to a deeper coupling of the system. Only new instances of Module Frames have to be generated and some methods have to be added to some of the existing Module Frames.

4.2 Adaptation and Refinement

The project as described above will result in an operational prototype development planning expert system. Given the time and resource limitations of the project, numerous components and refinements deemed necessary or very useful have to be excluded and left for further development. The open architecture and modular structure of the software system supports this incremental development style. Adding and interfacing additional components is made easy by the standardized interface structure and a number of generalized utilities.

Several of the extensions which we believe would add to the scope, power, and direct utility of the system have been discussed above. They include various additional models, extensions and refinements to the databases, some system's management software for data acquisition and database management, and eventually the generalization of many of the component modules to a broader range of applications.

The most important future development, however, will be the adaption of the system to the lessons to be learned from its first applications. There is no doubt that, all the effort to produce a directly useful system notwithstanding, many modifications will be required to make the system more directly useful in its specific institutional and user environment. Since we expect the system itself to open up new possibilities of development planning and thus shape its own institutional framework, this new style of the planning procedure will lead to new requirements for the system.

Anticipating the need to change and adapt, providing the flexibility to learn from experience, and being able to listen and respond to the user and his requirements formulated in reaction to the prototype system, is a basic feature of the overall approach. Rather than locking the user into the methodology of the system, it must invite modifications through its open architecture, keeping the cost of adaption and replacements low. The system must be viewed as an approach or a philosophy as much as a product, or rather a set of tools, that can be configured and reconfigured to meet ever-changing requirements.

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*) Although the representation is procedural in order to increase implementation speed, this is not a big drawback, because in a first prototype version the coordination problem is a very simple one.

Being intelligent also means being able to learn, and it is exactly this learning potential, the recognition that no formal system can ever be perfect but needs continuing adaptation to growing experience and changing conditions, that we believe adds a new dimension to our approach. Only if the system is perceived as useful by its users, will they use it in their day-to-day work and make it an integrated element of the planning and decision making process.

The ultimate criterion of being useful is to be used.

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