

Article: The New Times: a Model for the Millennium

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INTRODUCTION

The scene is a waterfront motel in Hampton Bays, Long Island, USA. It is a clear, bright early fall day in 1996. The summer crowds have gone, and the motel is all but abandoned. In an upstairs meeting room, a view of the bay framed in a large picture window, a group sits down at a scramble of chairs facing an easel with a blank flip chart. They are an American, two Germans, and an Indian by way of Canada. They are the embryo of a multinational group setting out to design the best bottom-up energy systems model in the world.

Prepared with a wish list of new modeling features desired by the ETSAP participants, the group begins setting down the mathematics that will define new the model, TIMES.

The group is led by Gary Goldstein, the ETSAP primary systems coordinator since 1991 when he returned to Brookhaven National Laboratory after a stint abroad. Gary took over MARKAL, then a mainframe computer model, converted it for desktop computers, and added the MARKAL User's Support System (MUSS), a shell that makes entering data and interpreting results easy. Now an independent contractor to ETSAP, Gary believes that the state of the art of computer hardware and software has advanced to the point where the successor to MARKAL is needed.

The others are Peter Schaumann and Günter Schmid of the Institute for Energy Research (IER) at the University of Stuttgart, and Amit Kanudia of Canada's *Groupe d'études et de recherche en analyse des décisions* (GERAD). They are to be joined by Tom Kram of the Netherlands Energy Research Foundation, Tomas Larsson of the Gothenburg University of Technology, Sweden, Richard Loulou of GERAD, Ken Noble of the Australian Bureau of Agricultural and Resource Economics (ABARE), Uwe Remme of IER, GianCarlo Tosato of the Italian Agency for New Technologies, Energy and the Environment (ENEA), and Denise van Regemorter of the Catholic University of Leuven, Belgium, as the core group designing the new model.

Fast-forward to November 1999. The semiannual meeting of ETSAP, this one in Bergen, the Netherlands. Between these two meetings, the group has met at ETSAP workshops in Oslo, Rome, Berlin, Turkey, Washington, D.C., and two workshops of their own, with continuing E-mail correspondence in between. After one more workshop held for two days at the Netherlands Energy Research Foundation in nearby Petten, Goldstein reports on the new model to the semiannual ETSAP workshop.

In general, the model is behaving as anticipated mathematically, he says. During the past months, three national teams have been converting their MARKAL databases to TIMES with the assistance of a MARKAL-to-TIMES (M2T) conversion utility as part of the task of validating the new model. In Canada, Kanudia has converted three provincial models, and he is developing a results analysis utility that will be joined with a basic report writer. Denise van Regemorter of Belgium reports that you need to start with a good understanding of both MARKAL and TIMES, with Gary available to deal with the details at times. Mario Contaldi reports that the Italian model runs quite smoothly, with results within 5 percent of MARKAL.

"With most of the core features available, TIMES is making progress through the validation phase, although there are still some idiosyncrasies to be sorted out in both the M2T conversion utility and the model itself," says Goldstein. The Netherlands plans to begin its model conversion, and other ETSAP partners are urged to do the same.

Ahead is the choice of the Expert Shell that will enable experienced MARKAL users to use TIMES, and then the User's Shell. The leading candidates are MESAP, by adding a thin layer to a full-featured energy data management system conceived by Christoph Schlenzig of IER, and ANSWER, the current system for working with MARKAL, developed by Ken Noble of ABARE.

The goal is to have a WORLD-TIMES model fully functioning by the spring 2000. Richard Loulou hopes to have a 20-country version running in time to do global bottom-up modeling for the Third Assessment Report of the Intergovernmental Panel on Climate Change.

TIMES is not the first model to be created with this extraordinary multinational participation. It's the second. MARKAL was originally developed by two teams with representatives from 16 countries, one working in the U.S. at Brookhaven National Laboratory and one in Germany at the Energy Research Center in Jülich. Designed 20 years ago to meet the differing requirements of 16 countries, MARKAL has the flexibility that has led to its being used in more than 40.

TIMES will greatly expand upon MARKAL's traditional strengths and inherent flexibility, building on the advanced features added to MARKAL over time. For example:

- TIMES represents emissions, and material and financial flows as well as energy
- TIMES facilitates the linkage of individual national models to examine trade in fuels, money, emission rights, and other commodities
- TIMES can be scaled to model energy systems from the level of a local community up to global regions
- TIMES can alter the product mix from refineries in response to needs
- TIMES allows for separate discount rates for different technologies and energy demand sectors
- TIMES can be linked with economic models for E³ (energy, economy, environment) optimization

What's new in TIMES

New features in TIMES include:

- A regional index to allow examination of trade issues and mapping to geographic information systems. This can be used to evaluate the effects of carbon emissions trading, carbon "leakage" from one country to another, and the implementation of the Clean Development Mechanism. The same feature makes it possible to evaluate infrastructure needs for electrical grid and gas transportation facilities.
- Vintaging of technologies, which allows for the analysis of early reduction credits and subsidies for less carbon-intensive or energy-intensive technologies.
- Time slices to any level of detail down to the hour of the day, not simply season and day/night. With this feature, for example, TIMES may be used to model the effects of time-of-use electrical rates on load curves.
- Variable time period lengths, which allow for the evaluation of the annual effects of carbon mitigation policies in the short term, together with five-year, ten-year, or even 50-year increments for evaluations in the intermediate and long term.
- Intertemporal equations to permit examination of retrofitting and life extensions options.
- Representation of the intensity of attributes, such as sulfur content of fuel
- A distinction between service life and economic life of technologies
- Independence of model year data from source year data, permitting data to be entered as obtained but analyzed for other years
- Direct correspondence of model data with source data
- An uncertainty index to allow for stochastic and fuzzy logic.

"TIMES builds on the best features of MARKAL and the Energy Flow Optimization Model (EFOM), a sister model to MARKAL widely used earlier in Europe," said Goldstein, "hence the acronym TIMES (The Integrated MARKAL-EFOM System). We think it will promote the consolidation and uniting of the E³ optimization community.

"MARKAL, while achieving unprecedented longevity as modeling systems go, has not benefited from a re-thinking of the basic approach to describe the Reference Energy System (RES) upon which it is based, nor the way the RES is depicted mathematically.

"With the experience gained over the past two decades applying MARKAL to real world problems, with the many fresh ideas arising from this experience, and with the expanding need for a detailed technology-oriented model that

can be scaled from the municipal level up to a multiregional global model, we decided to take on this challenging job."

TIMES adopts a generic concept to describe the components (commodities and processes) of an RES and its interconnections.

- *Commodities* are defined as the energy carriers, energy demands, materials, money, and emissions, that flow through the RES network.
- *Processes* are the means of transforming commodities from one form to another. A process is described by its capacity and activity, with the units of each explicitly defined by the user.

The flexible representation of processes in TIMES allows the relationship between individual flows to be depicted in a natural way to describe even the most complex processes.

The process box will allow inputs and outputs to be described in a flexible manner so that almost any (linear, for now) relationship may be depicted. This includes, but is not limited to:

- Tying input or output flows directly to either the capacity or overall activity of the process
- Establishing fixed proportions for various inputs or outputs
- Allowing minimum and/or maximum allocation levels to be specified for all inputs or outputs to/from a process that will then be optimized by the model, and
- Allowing an input in one time-slice to control output in another.

Data are organized by *attributes* that are either global to the model or provide knowledge of the nature of a piece, or time-series, of information to be associated with a process or commodity. An *attribute qualifier*, or index, provides further knowledge of the specific nature or particular instance of an attribute. Primary attribute qualifiers are:

- Region
- Time indexes that distinguish the years for a particular model run
- Time-slices that divide one year
- Boundaries: upper, lower, fixed, none
- Monetary units
- Process name
- Commodity groups, to relate commodities by type (energy, material, financial) or to identify commodities that determine the nature of the process (e.g., mix of crude oils to a refinery)
- Characteristic or indicator, to distinguish properties of a commodity for blending (e.g., sulfur content, octane level) or a source or price indicator for an import or export
- State-of-world, an uncertainty indicator corresponding to data according to perceived knowledge of the information when using stochastics.

Vintaging

In traditional systems engineering models, attributes usually have one time index, and the data generally relate to one specific future year. Without vintaging, the characteristics of any modeled technology are independent of the age structure of the stock of installations. However, the technical characteristics of an installation often change with aging. For example, the availability of power plants may increase at first as initial problems are overcome, and later decline due to more outages as parts wear out. Some changes over time may be independent of the technology itself, such as a rise in "fixed" operating and maintenance expense due to higher wages.

By vintaging installations, their technical characteristics depend upon the year of installation and the age structure of the stock. The change of attribute values over the lifetime of one vintage can be specified in TIMES using a function called SHAPE.

The objective function

The objective function of TIMES, which is minimized by the solution to the program, includes a number of innovations. The objective function is expressed as the discounted sum of annual costs minus revenues, so as to

provide year-by-year reporting of net costs.

- The model accepts technology-specific discount rates as well as a general discount rate. This is used for discounting the yearly payments of investment costs over the economic life of a technology.
- The model can represent *sunk costs* of materials and energy carriers, that is, those embedded in a technology at its inception. Examples are the uranium core of a nuclear reactor, or the steel embedded in an automobile. Unless these are represented in the RES, their cost should be included in the investment cost.
- The investment in new technology may not occur in a single year, but can be represented as a series of annual increments.
- Fixed and variable operating and maintenance costs.
- Decommissioning or dismantling costs are accepted, with an optional time lag that, for example, may be required for radioactive material to cool down.
- The recuperation of sunk materials can be credited when a facility is decommissioned.
- Any taxes or subsidies on investment, decommissioning, and fixed annual costs are accepted by the model.
- Payments made beyond the model's horizon, for decommissioning or recuperation, are reported separately.
- Salvage costs are reported as a single lump sum at the end of the horizon.
- Resource depletion costs are computed.
- When elastic demands are used in the model, the objective function includes the loss of welfare due to the reduction or increase in demands.


 [Figure 1, vol7-1-1.gif]

Figure 1: The annualized objective function handles repeated investments in long time periods, as shown here for light bulbs.

Figure 2. The annualized objective function represents delayed investments due to construction lead times, for example in nuclear plants as shown here, as well as decommissioning costs. (to be provided!)

When the validation and testing phase is completed, the formulation of TIMES will be expanded to include enhanced quality control, stochastics, and a linkage with the economic model MACRO, as well as other advanced features such as grouping technologies and sectors for selective representation, and learning curves for investment costs.

TIMES, a model for the millennium?

"Well, at least for the next decade or two," says Goldstein.