The TIMES model generator: Status of the code

Uwe Remme, Antti Lehtila, Gary Goldstein

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**Development**
- By ETSAP
- Implementation in GAMS

**TOOLS**
- VEDA-FE (Front End)
- VEDA Analyst

**TIMES**
(The Integrated MARKAL EFOM System)

**Methodology**
- Bottom-up Model
- Perfect competition
- Perfect foresight
- Optimisation (LP/MIP)

Min/Max Objective function
s.t.
Equations, Constraints
Decision Variables $\leftrightarrow$ Solution
Input parameters

**Features**
- Multi-region
- Inter-temporal
- Elastic demands
- Vintaging
- Load curve
- Endogeneous learning
Features of TIMES

• Flexible process description:
  • General process description with three process types: general processes (PRC), exchange processes (IRE) and storage processes (STG)
  • Ratios of input and output flows can be determined by optimization
  • Time slice operation according to commodity requirements
  • Direct access to all flow variables (e.g. for usage in user constraints, to associate emissions with fuels)

• Full vintaging of processes (optional by process):
  • Technical parameters of a process as a function of the vintage year
  • Shaping / decay of input parameters as a function of age

• User-controllable inter-/extrapolation of input data to model years:
  • Linear and log-linear interpolation, direct extrapolation or fill-in with EPS
  • Default rules if no options specified

• More accurate cost representation:
  • Annual cost accounting
  • Spread investment builds and payment
  • Investment leads (e.g., R&D and construction) and decommissioning
  • Splits of O&M components (e.g., labor)

Features of TIMES (contd.)

• High independence of data vs. model years achieved

• Flexible time periods:
  • Unequal period duration
  • Technical parameters of a process can be defined over a two-dimensional space of time (vintage × age)
  • Past investments based on vintage year not residual curves

• Flexible definition of time slices:
  • Three levels (seasonal, weekly, daynite) with an arbitrary number on each level
  • All time slice levels are available for all processes and commodities
  • Storage and load shift processes may operate between any time slices

• Flexible discounting options:
  • Technology-dependent discount rates, economic vs. technical lifetimes
  • Time-dependent discount rates at sector/technology level if desired
  • Optional mid-year discounting (default: beginning-of-year discounting)
Features of TIMES (contd.)

- User constraints:
  - All variables can be used in a user constraint
  - Possibility to define inter-temporal constraints
  - Possibility to define cumulative constraints over region or period
  - Option to formulate growth constraints

- Option to use elastic demands (linear staircase formulation)

- Endogenous technological learning (MIP approach, technology clusters)

- Option to define discrete capacity extensions (lumpy investments)

- Mechanisms to add extensions (model equations/variables, report routines) that can be turned-on/off (e.g. VTT, IER extensions)

- Connection to VEDA-BE via GAMS GAMS2VEDA utility (allowing user augmentation for addition data dumps including input data)

Recent modifications in the TIMES code

- Performance improvements (e.g. investment costs calculated in a similar fashion as salvage value)

- Bug fixes (e.g. ETL, elastic demand, objective function)

- Linkage with VEDA4-BE (primal variables, costs by type and prc/com, reduced costs, shadow prices of commodity balance and peaking eqn)

- Enhancements of the code:
  - Time-dependent discount rates
  - Option to use discrete capacity extension
  - Improvements in user constraints: easier formulation for growth constraints and addition of import/export flows as possible variables
Discrete capacity extension

- Capacity can only be added in different predefined block sizes resulting in a MIP problem.
- Blocks may have different specific investment costs, e.g. specific costs decrease with the block size.

\[
VAR_{\_\_\_\_N\_C\_A\_P_{r\_p}} = \sum_j VAR_{\_\_\_\_N\_D\_S\_C_{r\_p\_j\_i}} \cdot ncap_{\_\_\_\_\_d\_i\_s\_c_{r\_p\_j\_i}} \forall r_{p}, \forall p
\]
\[
\sum_j VAR_{\_\_\_\_N\_D\_S\_C_{r\_p\_j\_i}} = 1 \forall r_{p}, \forall p \quad (\Leftrightarrow \text{SOS1 set supported by some solvers})
\]
\[
VAR_{\_\_\_\_N\_D\_S\_C_{r\_p\_j\_i}} \in [0; 1]
\]

\(j\): index for binary variables
\(VAR_{\_\_\_\_N\_D\_S\_C_{r\_p\_j\_i}}\): binary variable
\(ncap_{\_\_\_\_\_d\_i\_s\_c_{r\_p\_j\_i}}\): allowable sizes of capacity extensions

Formulation of growth constraints

- Based on user constraints
- Possibility to define not only growth constraints but also phase-out constraints
- Growth constraints applicable to all variables
- More than one technology may be involved in a growth constraint, e.g.

\[
VAR_{\_\_\_\_C\_A\_P_{r\_p,Tech\_d}} \leq g_{r\_p,load}^{Tech\_d} \cdot VAR_{\_\_\_\_C\_A\_P_{r\_p-1,Tech\_d}} + g_{r\_p,load}^{Tech\_d} \cdot VAR_{\_\_\_\_C\_A\_P_{r\_p-1,Tech\_d}} + \text{const.}
\]
Performance of a multi-regional TIMES model

- Single region model
  - # processes: 986
  - # commodities: 411
  - # periods: 11
  - # timeslices: 4 (WD, WN, SD, SN)
- Each region is connected to all other regions by an exchange process (→ 105 exchange processes in the 15 region model, 300 in the 25 region model)

<table>
<thead>
<tr>
<th>Reduced matrix</th>
<th>1 region</th>
<th>15 regions</th>
<th>20 regions</th>
<th>25 regions</th>
</tr>
</thead>
<tbody>
<tr>
<td># rows</td>
<td>30,628</td>
<td>467,611</td>
<td>625,696</td>
<td>784,925</td>
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<tr>
<td># columns</td>
<td>25,234</td>
<td>387,826</td>
<td>521,516</td>
<td>657,450</td>
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<tr>
<td># nonzeros</td>
<td>230,532</td>
<td>3,487,429</td>
<td>4,663,164</td>
<td>5,845,675</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Memory usage before solver is called [MB]</th>
<th>1 region</th>
<th>15 regions</th>
<th>20 regions</th>
<th>25 regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Execution</td>
<td>13</td>
<td>347</td>
<td>542</td>
<td>781</td>
</tr>
<tr>
<td>Matrix generation</td>
<td>22</td>
<td>331</td>
<td>465</td>
<td>925</td>
</tr>
<tr>
<td>Barrier time</td>
<td>27</td>
<td>509</td>
<td>746</td>
<td>1678</td>
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<tr>
<td>Crossover time</td>
<td>4</td>
<td>227</td>
<td>490</td>
<td>1147</td>
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<tr>
<td>Reporting</td>
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<td>270</td>
<td>394</td>
<td>580</td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td>1684</td>
<td>2627</td>
<td>4811</td>
</tr>
</tbody>
</table>

(Using GAMS 21.3, CPLEX 9.0, Pentium 4, 3.2 GHz, 2 GB RAM)

Features implemented by IER and VTT that could be considered for adoption in the common code

- Market/product allocation constraints (IER, VTT)
  - Useful for calibrating / constraining market shares etc.
- Back-pressure / condensing mode availability of CHP processes (IER)
  - Useful for realistic representation of CHP heat production
- Commodity-dependent availability factors (VTT)
  - Useful for e.g. realistic representation of CHP heat production
  - Has been included as pending in the system documentation
- Generalized constraints for process flows (VTT)
  - Useful for modeling of many specific process characteristics
- Extended shaping parameters for vintaged processes (VTT)
  - Age-dependent emission factors and efficiencies
- … etc. (IER, VTT, …)
Future work

• VEDA-FE/TIMES evolution

• Documentation
  • System documentation
  • User guide, with process examples by type
  • Full sample model, including VEDA-BE tables

• Enhanced Quality Control of input data

• Streamlining of GAMS code

• Simplification of some basic input parameters (GAMS / VEDA-FE)

• Further enhancements of the methodology:
  • TIMES/MACRO
  • Stochastic programming
  • MARKAL features of interest