Recent Enhancement in GAMS

Jan-Hendrik Jagla  
Lutz Westermann

GAMS Software GmbH  
www.gams.de
GAMS Development Corp.  
www.gams.com
Then …

In Table 17.1 we list sizes and attributes of representative models that are “large” in the sense that they are near the limit of what is practical on a personal computer, along with the model generation time (GAMS) and solution time (solver), both in minutes. These examples were run on an 8 MHz AT with an 80287 coprocessor and 640K of RAM. The times shown are to give you a rough idea of what is possible: these are not precisely controlled benchmarks, and we have a host of performance improvements in mind for the near future.

Table 17.1: Problem Characteristics

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of Rows</th>
<th>Number of Columns</th>
<th>Number of Nonzeroes</th>
<th>Generation Time*</th>
<th>Solution Time*</th>
<th>Iterations</th>
<th>Solver</th>
</tr>
</thead>
<tbody>
<tr>
<td>DINAMICO</td>
<td>318</td>
<td>425</td>
<td>4156</td>
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<td>30.1</td>
<td>628</td>
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<tr>
<td>SARF</td>
<td>532</td>
<td>542</td>
<td>3949</td>
<td>37.7</td>
<td>115.8</td>
<td>2775</td>
<td>MINOS</td>
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<tr>
<td>PERTO</td>
<td>458</td>
<td>2968</td>
<td>7252</td>
<td>11.4</td>
<td>28.3</td>
<td>1368</td>
<td>ZOOM</td>
</tr>
<tr>
<td>CAMCSE</td>
<td>243</td>
<td>280</td>
<td>1356</td>
<td>0.8</td>
<td>7.0</td>
<td>189</td>
<td>MINOS</td>
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<tr>
<td>GANGES</td>
<td>274</td>
<td>357</td>
<td>1405</td>
<td>1.8</td>
<td>7.3</td>
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<td>MINOS</td>
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<tr>
<td>YEMCED</td>
<td>168</td>
<td>258</td>
<td>953</td>
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<td>7.6</td>
<td>600</td>
<td>ZOOM</td>
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<tr>
<td>BRYPF</td>
<td>281</td>
<td>618</td>
<td>3168</td>
<td>4.0</td>
<td>25.3</td>
<td>1551</td>
<td>ZOOM</td>
</tr>
</tbody>
</table>

*Measured in minutes.
The problem is too big for MINOS. ZOOM was used instead.
A nonlinear problem. 63% of the non-zeroes are nonlinear.
A nonlinear problem. 58% of the non-zeroes are nonlinear.
A mixed binary problem, with 55 binary variables (solved with a relative termination criterion of 10%).
A linear problem, solved using XMP which is contained within ZOOM.
... and now

<table>
<thead>
<tr>
<th>Type</th>
<th>s in 1988</th>
<th>s in 2008</th>
<th>Improvement Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>camcge</td>
<td>NLP</td>
<td>468</td>
<td>0.031</td>
</tr>
<tr>
<td>dinamico</td>
<td>LP</td>
<td>1986</td>
<td>0.125</td>
</tr>
<tr>
<td>egypt*</td>
<td>LP</td>
<td>1758</td>
<td>0.015</td>
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<tr>
<td>fertd*</td>
<td>MIP</td>
<td>2382</td>
<td>0.062</td>
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<tr>
<td>ganges</td>
<td>NLP</td>
<td>546</td>
<td>0.109</td>
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<td>sarf</td>
<td>LP</td>
<td>9210</td>
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<tr>
<td>yemcem*</td>
<td>MIP</td>
<td>510</td>
<td>0.140</td>
</tr>
</tbody>
</table>

* 1988 solver ZOOM, 2008 solver CPLEX 11.0.1
Agenda

- GAMS – An Introduction
- Solver Technology
- Productivity and Connectivity Tools
- Interfacing GAMS with other Applications
GAMS at a Glance

General Algebraic Modeling System

- Roots: World Bank, 1976
- Went commercial in 1987
- GAMS Development Corp.
- GAMS Software GmbH
- Broad academic & commercial user community and network
GAMS’ Fundamental concepts

Deployed models have often 15+ years lifecycle
  – Changing environment (Hardware, OS, Interface)
  – Improving solver technology

→ Different layers with separation of
  – model and data
  – model and solution methods
  – model and operating system
  – model and interface
GAMS’ Fundamental concepts

→ Models benefit from
  – Advancing hardware
  – Enhanced / new solver technology
  – Improved / upcoming interfaces to other systems

→ Backward compatibility

→ Protection of user investments
GAMS at a Glance

**General Algebraic Modeling System**

- Algebraic Modeling Language
- 25+ Integrated Solvers
- 10+ Supported MP classes
- 10+ Supported Platforms
- Connectivity- & Productivity Tools
  - IDE
  - Model Libraries
  - GDX, Interfaces & Tools
  - Grid Computing
  - Benchmarking
  - Compression & Encryption
  - Deployment System
  - …
## Supported Model Types (GAMS 22.7)

<table>
<thead>
<tr>
<th>Solver/Model type availability - 22.7</th>
<th>May 1, 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LP</strong></td>
<td><strong>MIP</strong></td>
</tr>
<tr>
<td>ALPHA-XCP</td>
<td></td>
</tr>
<tr>
<td>BARON 8.1</td>
<td>✔</td>
</tr>
<tr>
<td>BDMLP</td>
<td></td>
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<tr>
<td>CQIN</td>
<td></td>
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<tr>
<td>COPTOPT 3</td>
<td></td>
</tr>
<tr>
<td>CPLEX 11.0</td>
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<tr>
<td>DECIS</td>
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</tr>
<tr>
<td>DICOPT</td>
<td></td>
</tr>
<tr>
<td>KNITRO 5.1</td>
<td></td>
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<tr>
<td>LINDO/LGLOBAL 5.0</td>
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<tr>
<td>LOQ</td>
<td></td>
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<tr>
<td>MILES</td>
<td></td>
</tr>
<tr>
<td>MINOS</td>
<td></td>
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<tr>
<td>MIPSEQ 3</td>
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<tr>
<td>MPLSEQ</td>
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<td>RSMPL</td>
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<td>NLPEC</td>
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<td>OQNLP</td>
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<td>OSL 3.1</td>
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<td>PATH</td>
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<tr>
<td>SBE</td>
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<tr>
<td>SHOPT</td>
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<tr>
<td>XA</td>
<td></td>
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<tr>
<td>XPRESS 10.0</td>
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</tr>
</tbody>
</table>

**Contributed Plug-Play solvers**

- AMPLmate
- DEA
- Kestrel
## Supported Platforms (GAMS 22.7)

### Table: Supported Solvers/Platforms

<table>
<thead>
<tr>
<th>Solver/Platform availability 22.7</th>
<th>May 1, 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supported Platforms</strong></td>
<td></td>
</tr>
<tr>
<td><strong>GAMS</strong></td>
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<tr>
<td><strong>Win32</strong></td>
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<tr>
<td><strong>Solaris</strong></td>
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<tr>
<td><strong>Linux</strong></td>
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<tr>
<td><strong>Sun Sparc</strong></td>
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<tr>
<td><strong>HP ULX 11</strong></td>
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<tr>
<td><strong>DEC Alpha</strong></td>
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<tr>
<td><strong>IBM RS/6000</strong></td>
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<tr>
<td><strong>Mac PowerPC</strong></td>
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<tr>
<td><strong>NIX</strong></td>
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<tr>
<td><strong>SGI IRIX</strong></td>
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</table>

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<thead>
<tr>
<th><strong>Supported Solvers</strong></th>
<th><strong>Contributed Plug&amp;Play solvers</strong></th>
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<tr>
<td><strong>ALPHA</strong></td>
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<td><strong>BDMLP</strong></td>
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<tr>
<td><strong>COSIN</strong></td>
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<tr>
<td><strong>CONOPT 3</strong></td>
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<td><strong>CPLEX 11.0</strong></td>
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<td><strong>KNITRO 5.1</strong></td>
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<td><strong>LINDOGlobal 5.0</strong></td>
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<td><strong>MINOS</strong></td>
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<tr>
<td><strong>MOSEK 5</strong></td>
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<td><strong>MPsger</strong></td>
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<td><strong>MSNLB</strong></td>
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<td><strong>SNOPT</strong></td>
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<td><strong>XCA</strong></td>
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<tr>
<td><strong>XPRESS 18.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

1. GAMS distribution for HP 9000/HP-UX is 22.7.
2. GAMS distribution for SGI IRIX is 22.0.
Downloads by Platform

GAMS 22.5
~525 downloads/week

GAMS 22.6
~590 downloads/week

GAMS 22.7
~590 downloads a week
System Overview

Connectivity Tools
- Uniform Data Exchange:
  - ASCII
  - GDX (ODBC, SQL, XLS, XML)
- GDX Tools
- Component Libraries with Interfaces to C,C++,C#, Delphi, Fortran, Java, VB,…
- Ext. programs
  - EXCEL
  - MATLAB
  - GNUPLLOT, …
- CONVERT

Productivity Tools
- Integrated Development Environment
- Integrated Data Browser and Charting Engine
- Model Libraries
- Benchmarking and Deployment
- Model Debugger and Profiler
- Transparent and reproducible Quality Assurance and Testing System
- Data and Model Encryption
- Grid Computing
- Scenario Reduction
- MPSGE for general equilibrium modeling

Interactive

API / Batch

User Interfaces

GAMS Language Compiler and Execution System

Solvers
LP/MIP-QCP-MIQCP-NLP/DNLP-MINLP-CNS-MCP-MPEC, global, and stochastic

ALPHAEC, BARON, COIN, CONOPT, CPLEX, DECIS, DICOPT, KNITRO, LGO, LINDO, MINOS, MOSEK, OQNLP, PATH, SNOPT, XA, XPRESS, …
Improvements on all Frontiers

- **Solver Technology**
  - Updates for existing solvers
  - New solvers

- **Productivity Tools**
  - IDE improvements
  - Documentation and Wikis

- **Connectivity Tools**
  - Gams Data eXchange and GDX Tools
  - Component Libraries/APIs
Agenda

- GAMS – An Introduction
- Solver Technology
- Productivity and Connectivity Tools
- Interfacing GAMS with other Applications
Solver Updates

Continuous updates of existing solvers

- BARON 8.1
- Coin-OR Solvers
  - CoinCBC 2.1
  - CoinGLPK 4.22
  - CoinIpopt 3.3
  - CoinBonmin 0.99
- CPLEX 11.1
- LINDOGLOBAL 5.0
- MOSEK 5.0
- XPRESS 18.0
- ...
New Solvers

Continuous addition of new solvers, e.g.

- **CoinScip** [http://scip.zib.de/](http://scip.zib.de/)
  - LP/MIP solver developed at Zuse Institute Berlin (ZIB)
  - Branch-and-cut framework
  - Supports GAMS/BCH facility to allow additional control of the solution process
  - free for academic users

- In-core communication solvers
  - Bdmlpd, Conoptd, Cplexd, ...

- (Experimental) Extended Mathematical Programming
Improved Global Optimizers in GAMS

- Practical optimization problems are often nonlinear and non-convex, with discrete variables
- They may contain disconnected feasible regions with multiple local optima

→ Find the best of all local optima

- **BARON**
- **LINDOGLOBAL**  \[ \text{Proven global optimum} \]
- **LGO**
- **OQNLP/MSNLP**  \[ \text{Stochastic convergence to global optimum} \]
Global Benchmark Summary

- 250 models
- **MINLPs** from MINLIB
- timelimit: 600 sec
- gap tol.: 0%

- **Lindoglobal 5.0.1**
- **Baron 7.8.1**
Coin-OR

An initiative to spur the development of open-source software for the OR community

http://www.coin-or.org/

- A repository of currently ~30 open-source projects
  - Solvers
  - Interfaces
  - Tools

- An active OR community
  - Mailing lists
  - Google group
  - Wikis
The Coin-OR / GAMSLinks Project

https://projects.coin-or.org/GAMSLinks
Stefan Vigerske (Humboldt-University Berlin)

Goals

• easy access to COIN-OR solvers via GAMS
• broadening the audience of COIN-OR
• broadening the audience of GAMS
• help developers to connect their solvers to GAMS
• provide access to GAMS benchmarking and quality assurance tools
The Coin-OR / GAMSLinks Project

GAMS interfaces to open-source Solvers

• COIN-OR Linear Programming (CLP) and Branch and Cut (CBC)
  – state of the art LP and MIP solver from J. Forrest

• Gnu Linear Programming Kit (GLPK)
  – LP and MIP solver from A. Makhorin

• Interior Point Optimizer (IPOPT)
  – large scale NLP solver from A. Wächter
GAMS interfaces to open-source Solvers

- **Basic Open-source Nonlinear Mixed Integer programming (BONMIN)**
  - Branch and Cut based MINLP solver from P. Bonami et.al.

- **Lagrangian Global Optimizer (LaGO)**
  - Convexification and Branch and Cut based MINLP solver from I. Nowak and S. Vigerske

- **Solving Constraint Integer Programs (SCIP)**
  - LP/MIP solver developed at Zuse Institute Berlin (ZIB)
The Coin-OR / GAMSLinks Project

Available on
• Linux (32- and 64-bit x86-CPUs)
• MacOS Darwin (PowerPC-based G4/G5)
• Solaris (64-bit x86-CPUs)
• Windows (32-bit and 64-bit x86-CPUs)

Corresponding GAMS Systems distribute free coin solvers
• CoinIpopt
• CoinBonmin
• CoinCbc
• CoinGlpk
• CoinScip (academic only)
MIP Benchmark Summary

- 125 models: MIPs from LINLib
- timelimit: 1 hour
- gap tol.: 0.01%
- CPLEX 10.20
- CBC (Aug. ’07)
- GLPK 4.20
MINLP Benchmark Summary

- 149 models in MINLPLib
- MINLPs with < 1000 var.
- timelimit: 1 hour
- gap tol.: 1%
- BARON 7.8.1
- LaGO (Aug. ’07)
- BONMIN (Aug. ’07)
Performance Benchmark of MIP codes free for academic use by H. Mittelmann. Solution times are geometric means where unsolved instances were assigned a 2 hours solution time (time limit). Details at scip.zib.de

GAMS QA and testing supports maturing of COIN-OR solvers!

Coin-OR solvers enable GAMS to offer dependable free solvers!
Agenda

- GAMS – An Introduction
- Solver Technology
- Productivity and Connectivity Tools
- Interfacing GAMS with other Applications
Integrated Development Environment
Integrated Development Environment

- Project management
- Editor / Syntax coloring / Spell checking
- Launching and monitoring of (multiple) GAMS processes
- Listing file / Tree view / Syntax-error navigation
- Solver selection / Option selection
- GDX viewer
  - Data cube
  - Data export (e.g. to MS Excel)
  - Charting facilities
- Documentation
- Model libraries
Documentation

• Distributed Documentation
  – GAMS Users Guide
  – Expanded GAMS Users Guide (McCarl)
  – Solver Manuals
  – GAMS Utility Manuals

• Wikis
  – Support Wiki  http://support.gams-software.com
  – Interfaces Wiki  http://interfaces.gams-software.com
Distributed Model Libraries

- **GAMS Model Library**
  - Example and user-contributed models
  - Very often used as templates
  - Tests for
    - Solver robustness and correctness
    - Backward compatibility

- **GAMS Test Library**
  - Transparent and reproducible Quality Assurance Tests
  - Tests for
    - Solver correctness
    - Special functions
    - GAMS utilities
Distributed Model Libraries

- **GAMS Data Utilities Library**
  - Demonstration of the various utilities interfacing GAMS with other applications
  - e.g. GDX utilities

- **Practical Financial Optimization Models**
  Models of the forthcoming book

  "PRACTICAL FINANCIAL OPTIMIZATION – A Library of GAMS Models"

  by Consiglio, Nielsen and Zenios
Maintained libraries of established and varied set of both theoretical and practical test models:

- CONELib
- GLOBALLib
- LinLib
- MINLPLib
- MPECLib
- MPSGELib
- PrincetonLib
- XPRESSLib
- …
Binary Data Exchange

- Fast exchange of data
- Syntactical check on data before model starts
- Data Exchange at any stage (Compile and Run-time)
- Platform Independent
- Direct GDX interfaces and general API
- Scenario Management Support
- Full Support of Batch Runs

GDX Tools

- Invert
- IDE GDX Viewer
- GDXrank
- GDX2HAR / HAR2GDX
- GDXmerge
- GDXdump
- MDB2GMS
- GDXdifff
- GDXcopy

GAMS

GDX

SOLVER
GAMS in Control

GAMS Model

Direct GDX Interface

External Database

Import

Direct GDX Interface

External Database

Export

GUIs
Application in Control

Creating Input

GDX API

GDX Container

GAMS (Executable / DLL)

Call GAMS

Reading Solution

GDX API

GDX Container
Calling GAMS from an Application

Works from basically every environment

- MS Office Application / VBA
- Programming languages:
  - C, C++, C#
  - Delphi
  - Java
  - VB.NET
  - Fortran
- Web application (server side)
- ERP Systems: Oracle, SAP
- ...
Interfacing with GIS Applications

Increase in Ktons Per Year
- Less Than 0
- 0 - 199
- 200 - 1000
- 1000 - 3000
Interfacing with MATLAB

Figure 1: US dollar short rate scenarios

Figure 2: Short vs. long rates
Interfacing with GNUplot
Interfacing with Web Applications
Interfacing with Individual Front Ends
Distributed APIs

- Component Libraries
  - GAMS
  - GDX
  - Option

- Interfaces for
  - C, C++, C#
  - Delphi
  - Fortran
  - Java
  - VBA, VB.Net

- Examples/Documentation
## Agenda

<table>
<thead>
<tr>
<th>Section</th>
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<tbody>
<tr>
<td>GAMS – An Introduction</td>
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<td>Solver Technology</td>
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<tr>
<td>Productivity and Connectivity Tools</td>
</tr>
<tr>
<td>Interfacing GAMS with other Applications</td>
</tr>
</tbody>
</table>
Sample GAMS Applications

- Integrated Model of the US Electricity, Coal and Emission Markets
  → GAMS model is in control

- Hotdip Galvanizing Scheduling Model
  → Application is in control
Integrated US Energy Model

Coal and Gas Market
- Coal Class Costs and Supply, Coal Transportation Costs
- Coal Class Expansion
- Coal Usage Penalties
- Gas Cost and Supply, Gas Basis Differential

Energy Market
- Coal, Gas, Oil and Other Power Plants and Units
  - Unit Expansion
  - Electricity Transmission Costs and Capacities
  - Electricity Demand and Reserve Margin

Emission Market
- Air Pollutants
  - Clean-up Equipments, Combinations, Efficiencies and Costs
  - Emission Limits
  - Allowance Pools and Trading Rules

Least Cost Optimization
Varying Size of the Problem

- 7,500,000 Variables
- 3,500,000 Constraints
- 5,000,000
- 6 GB
- 1.3 GB
- 26,000,000 Non-zero Entries
- 900,000
- 1,400,000
- 5,000,000
- 40 min
- 13 hours
- 47
Layout of the Model

Integrated US Energy Model

Data Import Module
Data Manipulation Module
Solution Module
Report Module

GDX Container
GDX Container
GDX Container
GDX Container

GDX Container
MS Excel

GDX Container
MS Excel
Hot-dip Galvanizing Scheduling Problem

• **Given**
  – Set of jobs
  – Gas usage for reheating job i after job j is completed
  – Set of jobs not allowed to follow each other
  – Gas costs

• **Wanted:**
  – Schedule minimizing total gas costs
Hot-dip Galvanizing Scheduling Problem

- Can be formulated as a TSP like Model
- Need of subtour elimination constraints

- Single ‘Brute force’ model cannot be solved
- Algorithmic Approach using dynamic cuts
GAMS Beta Distribution 22.8 is available for download

http://beta.gams-software.com

- New Solver Libraries, e.g.
  - CPLEX 11.1
  - Coin-OR Solvers
- Experimental Solvers offering in-core communication
- Two new Model Libraries
- New utilities (gdx2xls, invert, xlstalk)
- …
Contacting GAMS

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Fax: +1 202 342 0181
http://www.gams.com
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support@gams.com