AMPL in the Cloud

Using Online Services to Develop and Deploy Optimization Applications through Algebraic Modeling

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Using Online Services to Develop and Deploy Optimization Applications through Algebraic Modeling

Optimization modeling systems first appeared online almost 20 years ago, not long after web browsers came into widespread use. This presentation describes the evolution of optimization alternatives in what has come to be known as cloud computing, with emphasis on the role of the AMPL modeling language in making models easy to develop and deploy. We start with the pioneering free NEOS Server, and then compare more recent commercial offerings such as Gurobi Instant Cloud; the benefits of these solver services are readily leveraged through their use with the AMPL modeling tools. We conclude by introducing QuanDec, which creates web-based collaborative applications from an AMPL models.

Word cloud, exhibitor descriptions

The Optimization Modeling Cycle

Steps

- Communicate with problem owner
- Build model
- Prepare data
- Generate optimization problem
- Submit problem to solver
  - Gurobi, Knitro, CPLEX, Xpress, CONOPT, MINOS, . . .
- Report & analyze results
- ***Repeat!***

Goals for optimization software

- Do this quickly and reliably
- Get results before client loses interest
- ***Deploy for application***

Optimization Modeling Languages

Two forms of an optimization problem

- Modeler's form
  - Mathematical description, easy for people to work with
- Algorithm's form
  - Explicit data structure, easy for solvers to compute with

Idea of a modeling language

- ***A computer-readable modeler's form***
  - You write optimization problems in a modeling language
  - Computers translate to algorithm's form for solution

Advantages of a modeling language

- Faster modeling cycles
- More reliable modeling
- More maintainable applications

Algebraic Modeling Languages

Formulation concept

- Define data in terms of sets & parameters
  - Analogous to database keys & records
- Define decision variables
- Minimize or maximize a function of decision variables
- Subject to equations or inequalities
  that constrain the values of the variables

Advantages

- Familiar
- Powerful
- Proven

AMPL

Features

- Algebraic modeling language
- Built specially for optimization
- Designed to support many solvers

Design goals

- Powerful, general expressions
- Natural, easy-to-learn modeling principles
- Efficient processing that scales well with problem size

3 ways to use . . .

3 Ways to Use AMPL

Command language

- Browse results & debug model interactively
- Make changes and re-run

Scripting language

- Bring the programmer to the modeling language

Programming interface (API)

- Bring the modeling language to the programmer

Example: Roll Cutting

Motivation

- Fill orders for rolls of various widths
  - by cutting raw rolls of one (large) fixed width
  - using a variety of cutting patterns

Optimization model

- Decision variables
  - number of raw rolls to cut according to each pattern
- Objective
  - minimize number of raw rolls used
- Constraints
  - meet demands for each ordered width

Roll cutting

Mathematical Formulation

Given

W set of ordered widths

n number of patterns considered

and

a_{ij} occurrences of width i in pattern j, for each $i \in W$ and $j = 1, \ldots, n$

b_i orders for width i, for each $i \in W$

Roll cutting

Mathematical Formulation *(cont'd)*

Determine

X_j number of rolls to cut using pattern j,
for each $j = 1, \ldots, n$

to minimize

$\sum_{j=1}^{n} X_j$

total number of rolls cut

subject to

$\sum_{j=1}^{n} a_{ij} X_j \geq b_i$, for all $i \in W$

number of rolls of width i cut
must be at least the number ordered

AMPL Formulation

Symbolic model

```
set WIDTHS;
param orders {WIDTHS} > 0;

param nPAT integer >= 0;
param nbr {WIDTHS,1..nPAT} integer >= 0;

var Cut {1..nPAT} integer >= 0;

minimize Number:
   sum {j in 1..nPAT} Cut[j];

subj to Fulfill {i in WIDTHS}:
   sum {j in 1..nPAT} nbr[i,j] * Cut[j] >= orders[i];
```

$$\sum_{j=1}^{n} a_{ij} X_j \geq b_i$$

AMPL Formulation *(cont'd)*

Explicit data (independent of model)

```
param: WIDTHS: orders :=
         6.77    10
         7.56    40
        17.46    33
        18.76    10 ;

param nPAT := 9 ;

param nbr:  1  2  3  4  5  6  7  8  9 :=
     6.77   0  1  1  0  3  2  0  1  4
     7.56   1  0  2  1  1  4  6  5  2
    17.46   0  1  0  2  1  0  1  1  1
    18.76   3  2  2  1  1  1  0  0  0 ;
```

Command Language

Model + data = problem instance to be solved

```
ampl: model cut.mod;
ampl: data cut.dat;

ampl: option solver cplex;

ampl: solve;

CPLEX 12.6.3.0: optimal integer solution; objective 20
3 MIP simplex iterations

ampl: option omit_zero_rows 1;
ampl: option display_1col 0;

ampl: display Cut;

4 13   7 4   9 3
```

Command Language *(cont'd)*

Solver choice independent of model and data

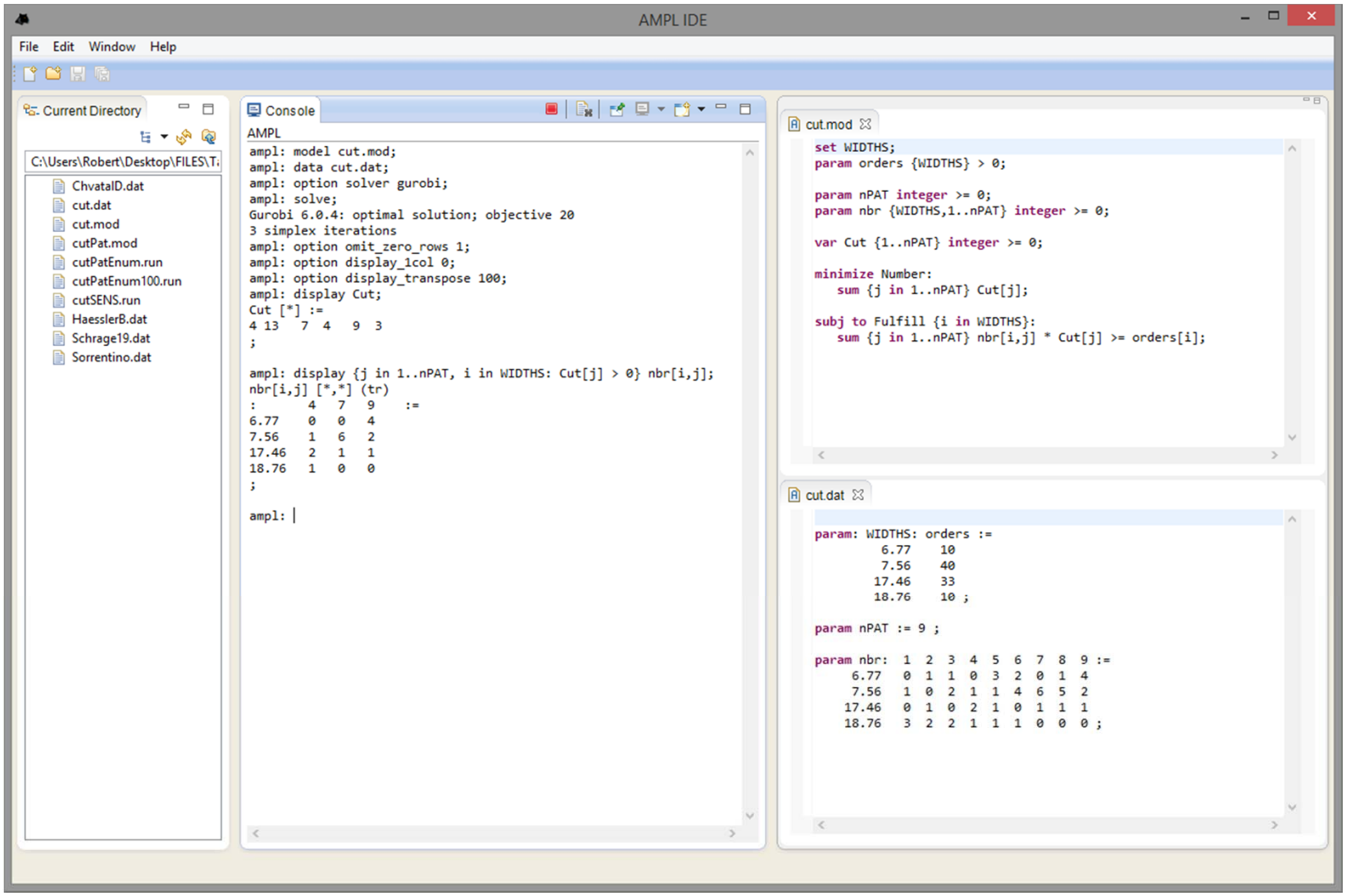
```
ampl: model cut.mod;
ampl: data cut.dat;

ampl: option solver gurobi;

ampl: solve;

Gurobi 6.5.0: optimal solution; objective 20
3 simplex iterations

ampl: option omit_zero_rows 1;
ampl: option display_1col 0;

ampl: display Cut;

4 13   7 4   9 3
```

Command Language *(cont'd)*

Results available for browsing

```
ampl: display {j in 1..nPAT, i in WIDTHS: Cut[j] > 0} nbr[i,j];
:       4   7   9  :=                                  # patterns used
6.77    0   0   4
7.56    1   6   2
17.46   2   1   1
18.76   1   0   0

ampl: display {j in 1..nPAT} sum {i in WIDTHS} i * nbr[i,j];
1 63.84   3 59.41   5 64.09   7 62.82   9 59.66        # pattern
2 61.75   4 61.24   6 62.54   8 62.0                   # total widths

ampl: display Fulfill.slack;
 6.77  2                                               # overruns
 7.56  3
17.46  0
18.76  3
```

IDE for Command Language



Computing in the Cloud

Client side

- Local computing device owned by the user
  - Company, organization, university, individual
- Client application run by the user on the local device

Server side

- Remote computing facility owned by a provider
  - Company, organization, university
- Service running automatically at the remote facility

AMPL
^ *Optimization in the Cloud*

Local modeling system, remote solver

- NEOS Server
- Gurobi Instant Cloud

Local analysis tools, remote model

- QuanDec

. . . a variety of AMPL interface alternataives

NEOS Server www.neos-server.org

Network Enabled Optimization System

- Originated 1995 at Argonne National Laboratory
  - U.S. Department of Energy
- Since 2011 at Wisconsin Institutes for Discovery
  - University of Wisconsin, Madison

Free "optimization on demand"

- Over 40 solvers
- Several optimization modeling languages

NEOS Server

Architecture

Distributed workstations

- Offer varied inputs & solvers
- Process submissions on demand
- Contributed by varied organizations

Central scheduler

- Receives and queues submissions
- Sends submissions to appropriate workstations
- Returns results

Minimal hands-on management

- *Distributed:* Install NEOS software on workstations
- *Central:* Update server database of workstation locations and abilities

NEOS Server

Original Facilities

Local submission clients

- Email
- Website
- NEOS submission tool

Problem description formats

- Linear: MPS and other solver files
- Nonlinear: Fortran or C programs
  - automatic differentiation of programs

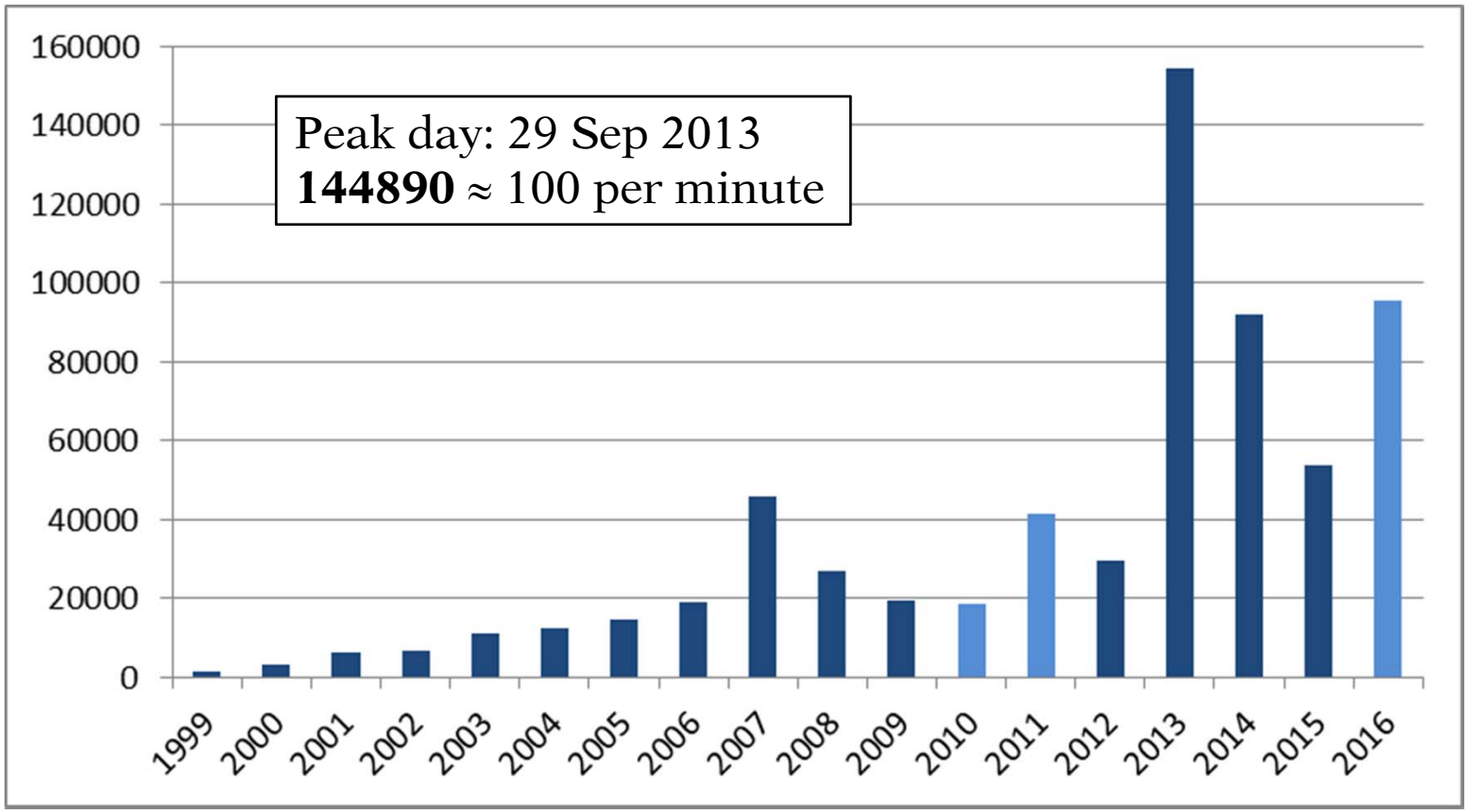
W. Gropp and J.J. Moré, 1997. **Optimization Environments and the NEOS Server**. *Approximation Theory and Optimization,* M. D. Buhmann and A. Iserles, eds., Cambridge University Press, 167-182.

J. Czyzyk, M.P. Mesnier and J.J. Moré, 1998. **The NEOS Server**. *IEEE Journal on Computational Science and Engineering* **5**(3), 68-75.

NEOS Server

Impact: Total Submissions

Monthly rates since 1999

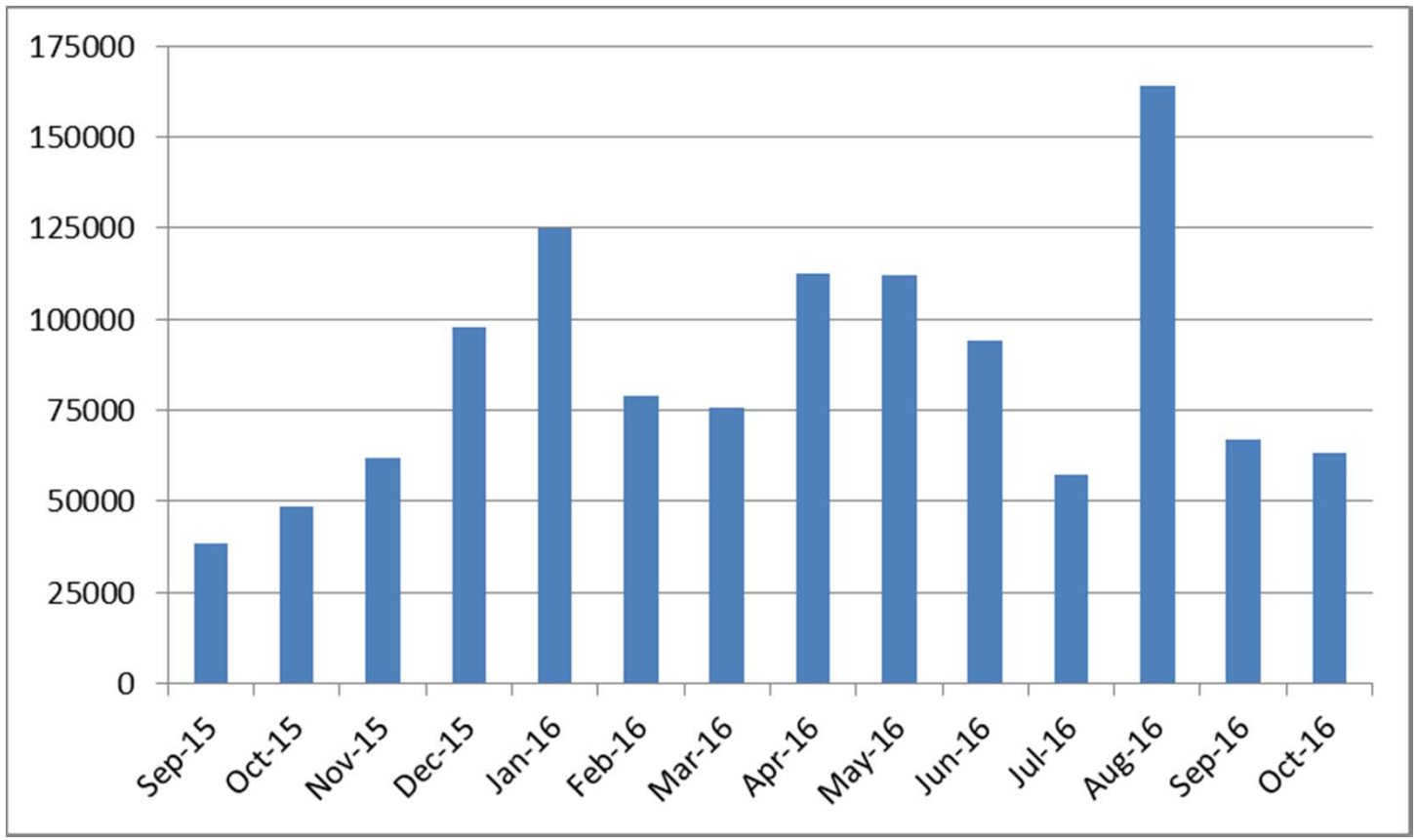


45000/month ≈ one per minute

NEOS Server

Impact: Recent Submissions

Monthly rates for past year



45000/month ≈ one per minute

NEOS Server

Assessment

Strengths

- Free
- Choice of solvers
  - Every popular solver available
- Easy to use
  - No account setup
  - No advance scheduling

Weaknesses

- Stand-alone focus: submission of "solve jobs"
- Non-profit management
  - Limited support & development
  - No guarantee of confidentiality
  - No guarantee of performance

NEOS Server

Recent Enhancements

More flexible server infrastructure

- Based on HTCondor "high-throughput computing"

Secure user authentication

- Option to register and sign in when submitting
- Potential advantages for registered clients
  - priority job execution
  - data security
  - "more services and better customized experiences"

Modeling Languages in NEOS

Modeling language inputs

- AMPL model, data, commands files
- GAMS model, options, gdx files

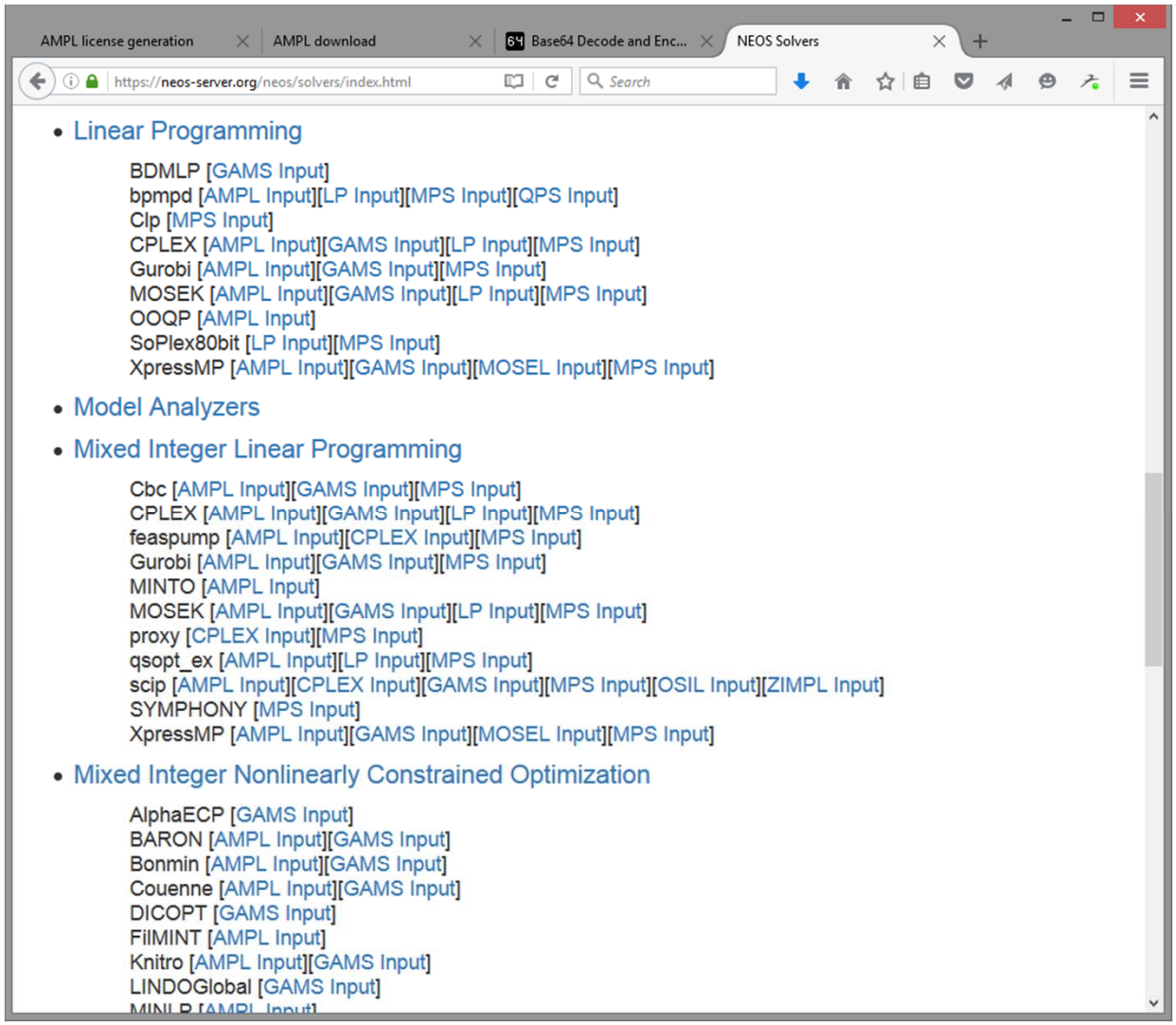
Modeling language operation

- User chooses a solver and a language
- NEOS scheduler finds a compatible workstation
- NEOS workstation invokes modeling language system with given inputs
- Modeling language system invokes solver

E.D. Dolan, R. Fourer, J.J. Moré and T.S. Munson,
Optimization on the NEOS Server. *SIAM News* **35:**6
(July/August 2002) 4, 8–9. www.siam.org/pdf/news/457.pdf

NEOS Server

Solver & Language Listing

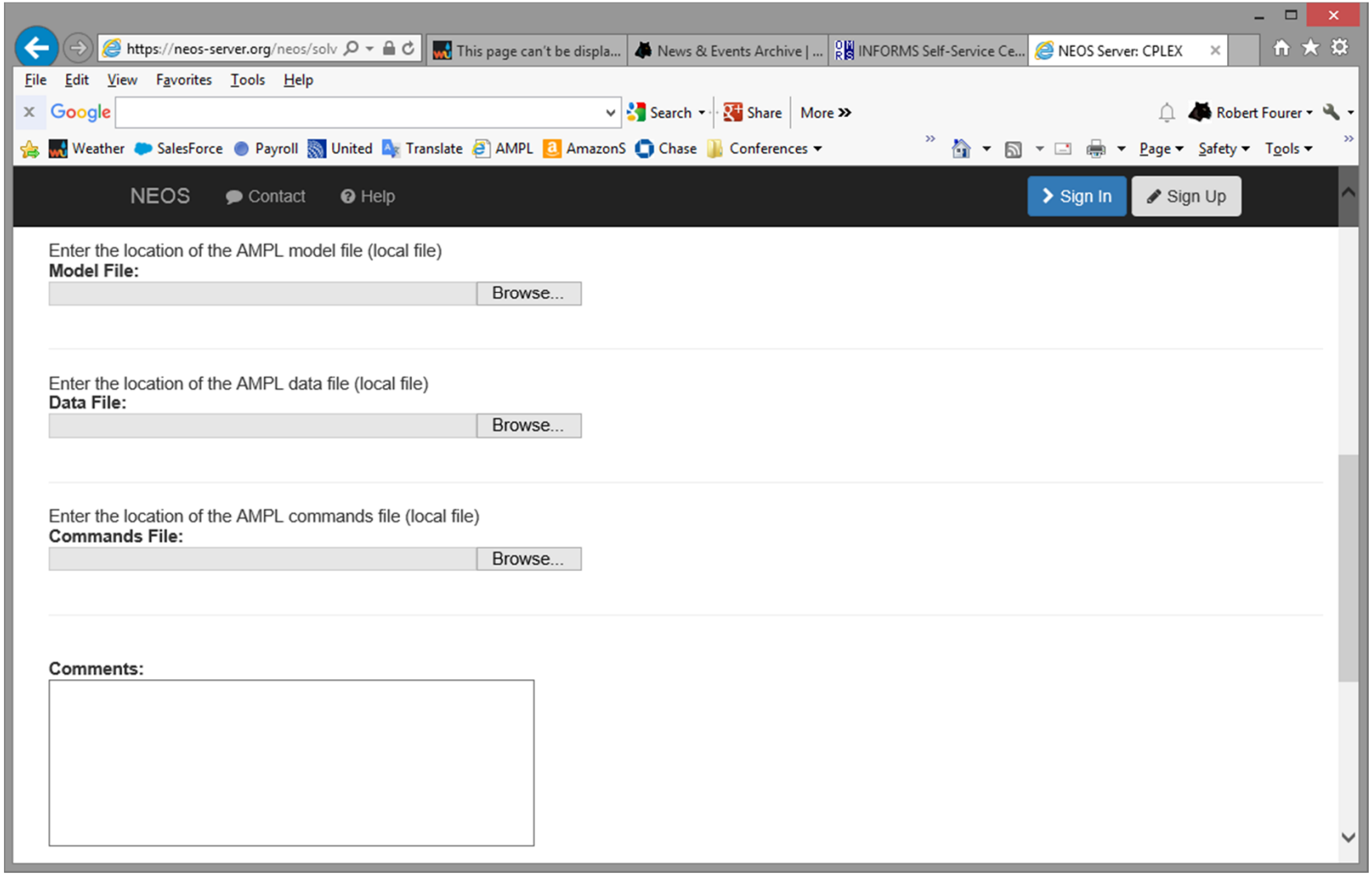


NEOS Server

AMPL Input Page

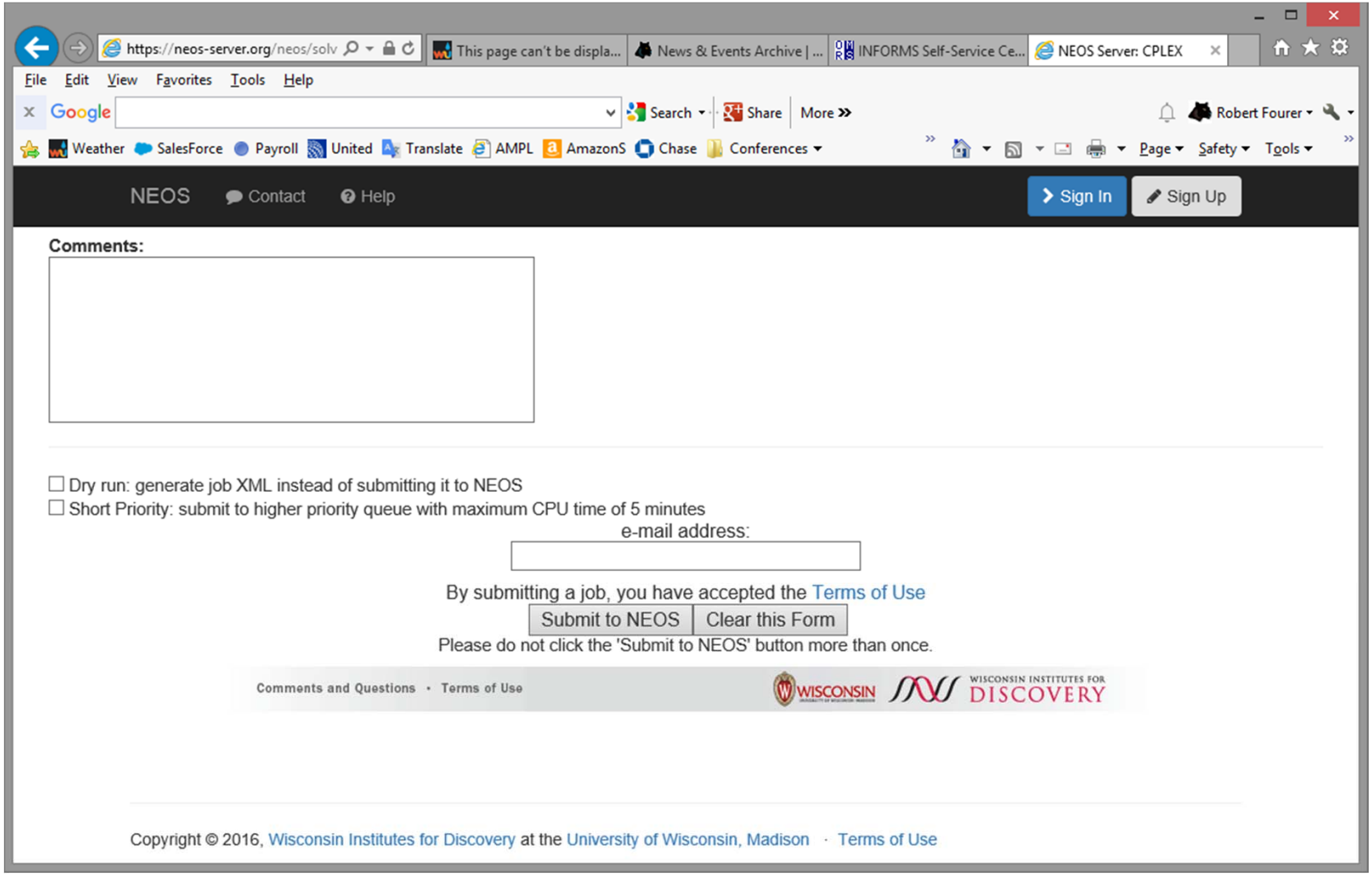
NEOS Server

AMPL Input Page



NEOS Server

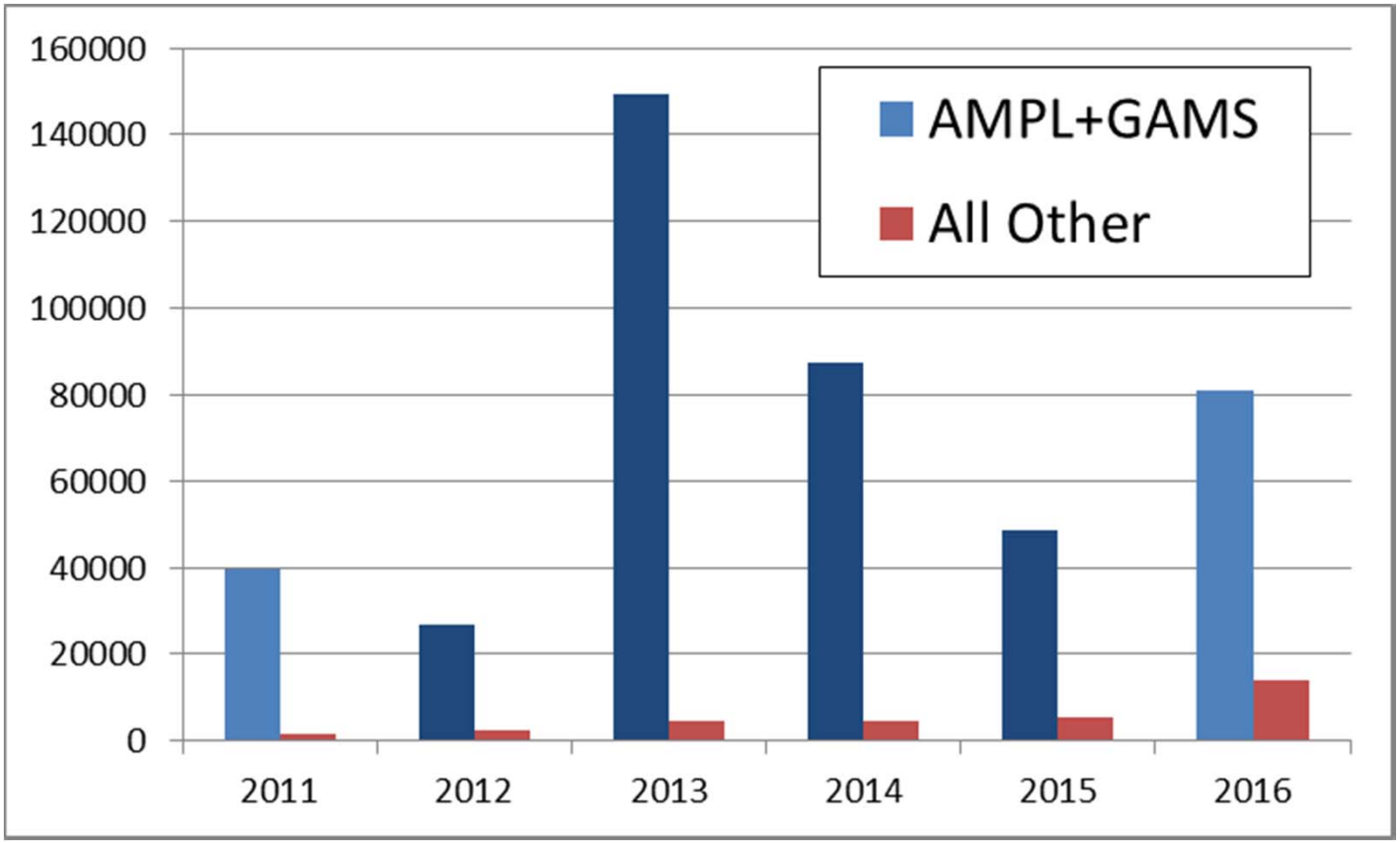
AMPL Input Page



NEOS Server

Impact: Modeling Languages

Monthly rates since 2011



NEOS Server

Modeling Systems as NEOS Clients

New "solvers"

- Kestrel for AMPL
- Kestrel for GAMS

Familiar operation

- Choose Kestrel as the local "solver"
- Set an option to choose a real solver on NEOS
- Initiate a solve and wait for results

E.D. Dolan, R. Fourer, J.-P. Goux, T.S. Munson and J. Sarich, **Kestrel: An Interface from Optimization Modeling Systems to the NEOS Server.** *INFORMS Journal on Computing* **20** (2008) 525–538. dx.doi.org/10.1287/ijoc.1080.0264

NEOS Server

AMPL Interactive Session

```
ampl: model sched1.mod;
ampl: data sched.dat;

ampl: let least_assign := 16;

ampl: option solver kestrel;
ampl: option kestrel_options 'solver=cplex';

ampl: solve;

Connecting to: neos-server.org:3332
Job 4679195 submitted to NEOS, password='JMNRQoTD'

Check the following URL for progress report :

http://neos-server.org/neos/cgi-bin/nph-neos-
solver.cgi?admin=results&jobnumber=4679195&pass=JMNRQoTD

Job 4679195 dispatched
password: JMNRQoTD

---------- Begin Solver Output -----------

Job submitted to NEOS HTCondor pool.
```

NEOS Server

AMPL Interactive Session

```
---------- Begin Solver Output -----------

Job submitted to NEOS HTCondor pool.

CPLEX 12.6.2.0: optimal integer solution; objective 265.9999999999943
135348 MIP simplex iterations
17430 branch-and-bound nodes

ampl: option omit_zero_rows 1, display_1col 0;

ampl: display Work;

Work [*] :=

  1 16    11 16    36 19    72 20    82 20   106 16   114 20   125 20
  3 16    29 16    66 17    79 19   104 19   112 16   121 16
;

ampl:
```

NEOS Server

Kestrel Impact

Some success

- 2013 and 2014:
  Peaked at over 500,000 submissions
- 2015:
  Dropped to only about 30,000 submissions
- 2016:
  Up to over 100,000 submissions so far

Kestrel Assessment

Strengths

- Powerful local client for modeling
- NEOS facilities for solving

Weaknesses

- Limited support & development
- Not all NEOS solvers available
- Local solver software is strong competition . . .
  - Bundled with modeling languages
  - Free for trial use
  - Free for course and academic use

More Recently . . .

NEOS in Solver Studio

- Excel add-in using
  AMPL/GAMS models, NEOS solvers

Optimization Services

- Fully distributed, decentralized alternative to NEOS

IBM Decision Optimization on Cloud

- "DropSolve" service similar to NEOS
- "DOcplexcloud API" like NEOS API

Gurobi Cloud Services for Optimization

- Gurobi cloud for Amazon Web Services
- ***Gurobi instant cloud***

Gurobi 7.0 Instant Cloud cloud.gurobi.com

Client side

- Standard Gurobi installation
- Cloud license

Server side

- Compute server for Gurobi solver
  - Single-machine solves
  - Distributed MIP solves
  - Distributed tuning
- Server pools with load balancing

. . . hosted on Amazon Web Services

"Cloud computing technology is changing quickly. Please check these documents periodically to ensure you have the latest instructions for the Gurobi Cloud."

Gurobi Instant Cloud for AMPL

Client side

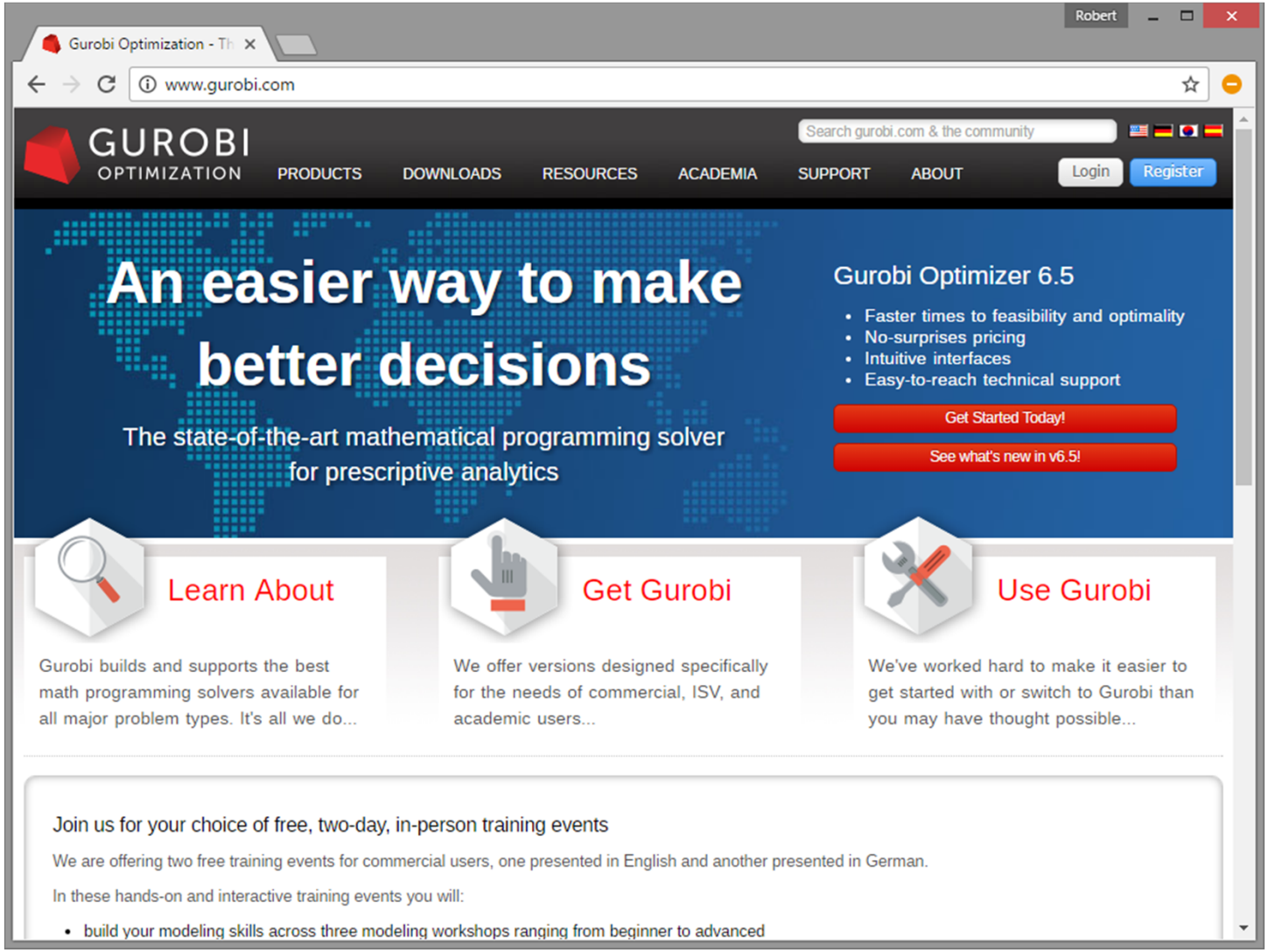
- AMPL installation (command-line or IDE)
- Standard Gurobi-for-AMPL installation

Server side

- Gurobi compute server
- Gurobi optimizer

Gurobi Instant Cloud for AMPL

www.gurobi.com

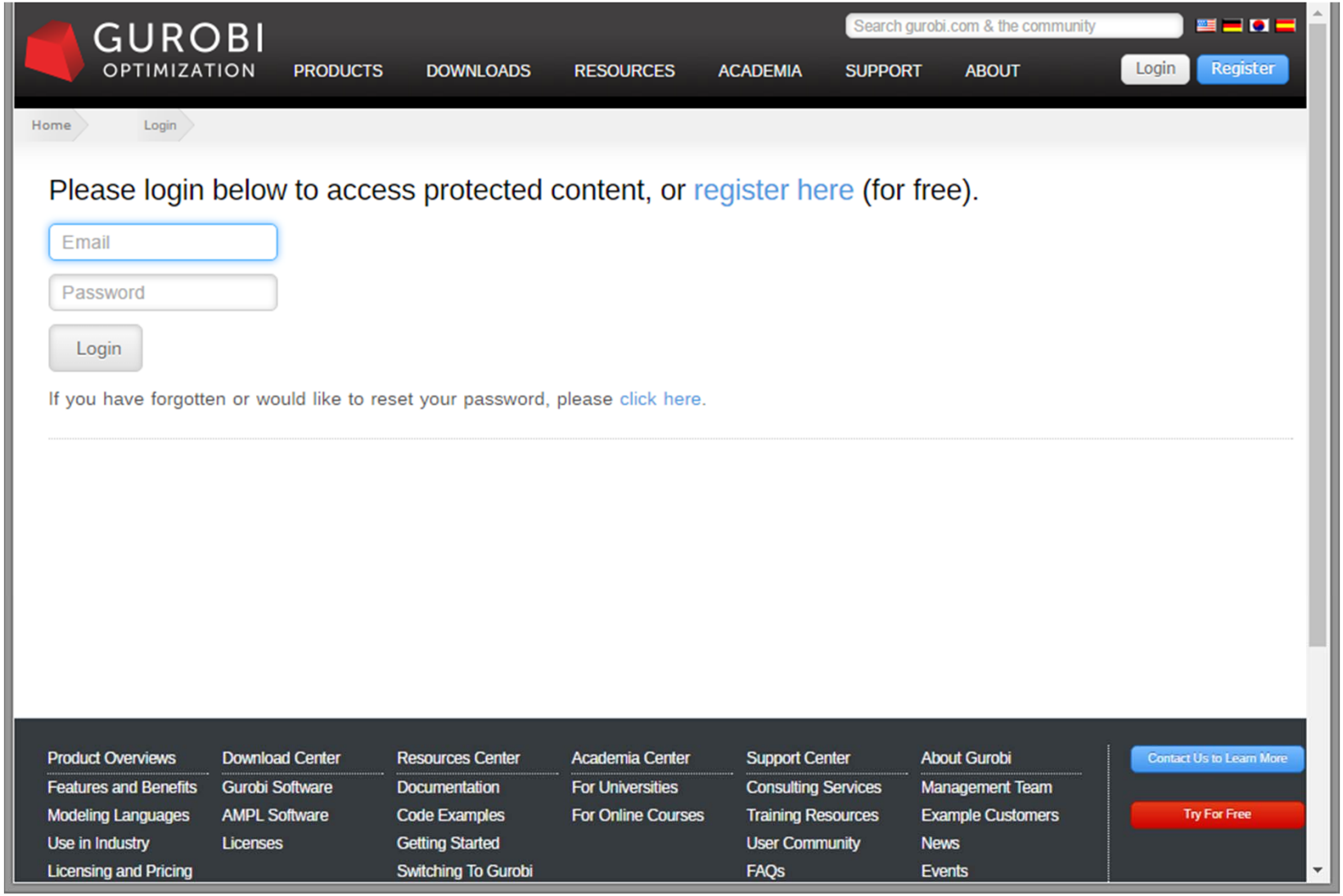


Gurobi Instant Cloud for AMPL

www.gurobi.com

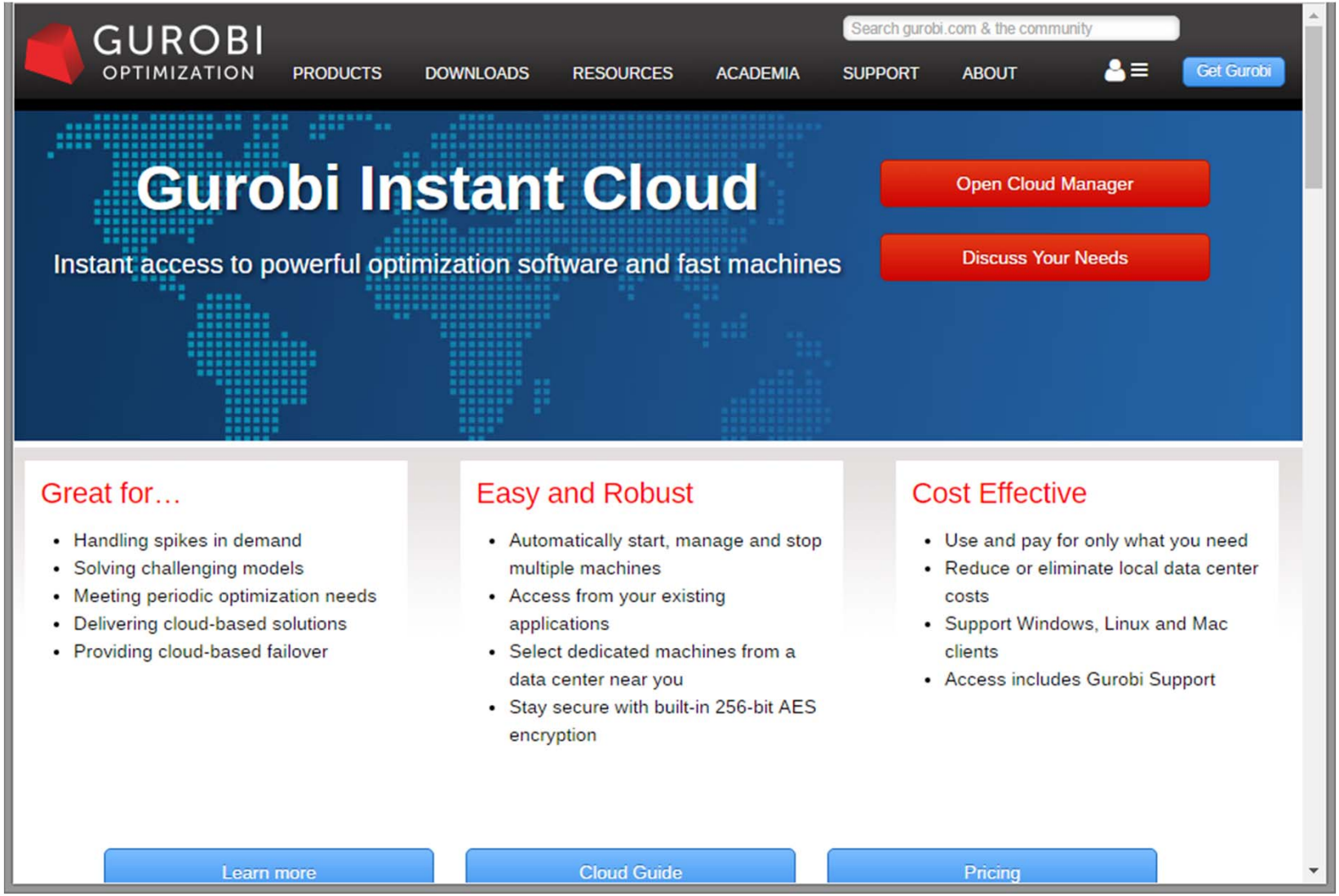
Gurobi Instant Cloud for AMPL

www.gurobi.com



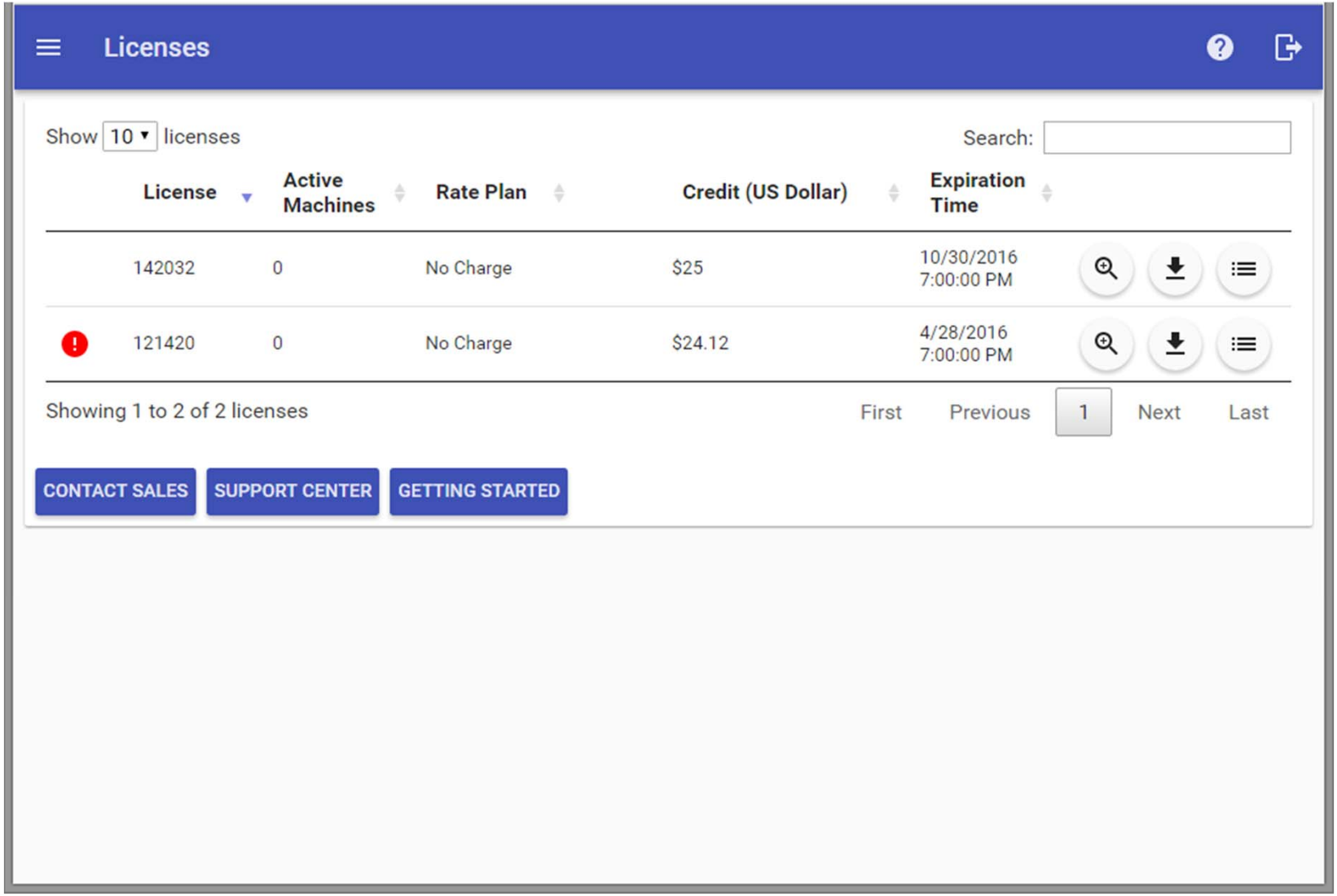
Gurobi Instant Cloud for AMPL

ngcloud.gurobi.com



Gurobi Instant Cloud for AMPL

View Available Licenses



Gurobi Instant Cloud for AMPL

Get Gurobi License File

```
# This is a license file created by the Gurobi Instant Cloud
# Created on Mon, 17 Oct 2016 20:46:26 GMT
# License Id: 142032
# Place this file in your home directory or one of the following
# locations where XXX is the Gurobi Optimizer version you are using:
#    * C:\gurobi\ or C:\gurobiXXX\ on Windows
#    * /opt/gurobi/ or /opt/gurobiXXX/ on Linux
#    * /Library/gurobi/ or /Library/gurobiXXX/ on Mac OS X
# Or set environment variable GRB_LICENSE_FILE to point to this file
# Do not share this license file because it contains your secret key

CLOUDACCESSID=fedf3901-04f1-44d7-9725-e36c1c3f70f6
CLOUDKEY=0v9XdWrDQLiE3EiAAEKtFw
CLOUDHOST=ngcloud.gurobi.com
```

Gurobi Instant Cloud for AMPL

Use with AMPL: *Setup*

```
ampl: model multmip3.mod;
ampl: data multmip3.dat;

ampl: option solver gurobi;

ampl: option gurobi_options
ampl?   'cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6 \
ampl?    cloudkey=0v9XdWrDQLiE3EiAAEKtFw';

ampl:
```

Gurobi Instant Cloud for AMPL

Use with AMPL: *Startup*

```
ampl: model multmip3.mod;
ampl: data multmip3.dat;

ampl: option solver gurobi;

ampl: option gurobi_options
ampl?   'cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6 \
ampl?    cloudkey=0v9XdWrDQLiE3EiAAEKtFw';

ampl: solve;

Gurobi 7.0.0: cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6
cloudkey=0v9XdWrDQLiE3EiAAEKtFw

Waiting for cloud server to start.........
```

Gurobi Instant Cloud for AMPL

Use with AMPL: *Solve*

```
ampl: model multmip3.mod;
ampl: data multmip3.dat;

ampl: option solver gurobi;

ampl: option gurobi_options
ampl?   'cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6 \
ampl?    cloudkey=0v9XdWrDQLiE3EiAAEKtFw';

ampl: solve;

Gurobi 7.0.0: cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6
cloudkey=0v9XdWrDQLiE3EiAAEKtFw

Waiting for cloud server to start.............
Capacity available on 'default' cloud pool - connecting...
Established 256-bit AES encrypted connection

Gurobi 7.0.0: optimal solution; objective 235625
289 simplex iterations
25 branch-and-cut nodes
plus 35 simplex iterations for intbasis

ampl:
```

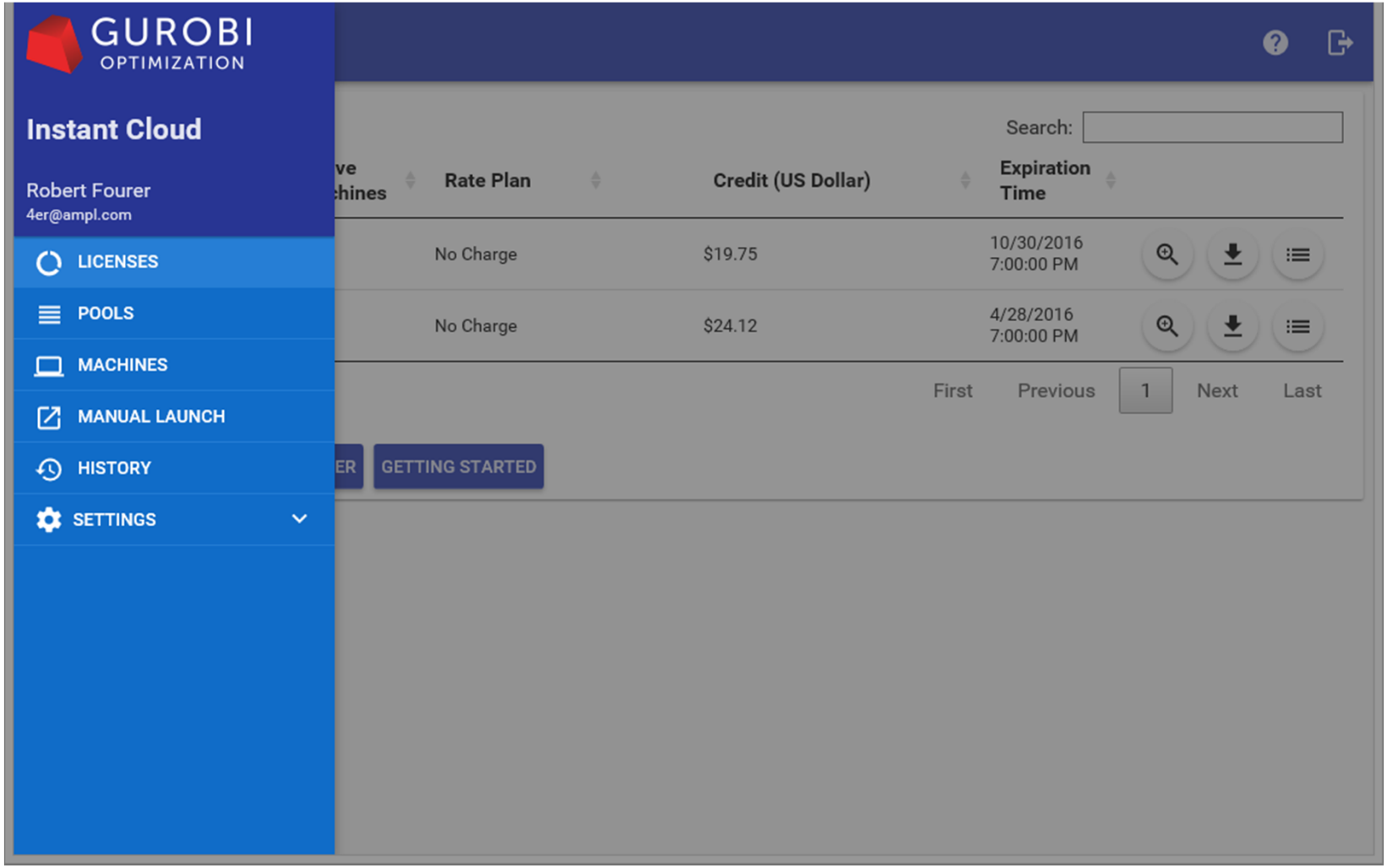
Gurobi Instant Cloud for AMPL

Use with AMPL: *Continue*

```
ampl: display {i in ORIG, j in DEST} sum {p in PROD} Trans[i,j,p];

:      DET   FRA   FRE   LAF   LAN   STL   WIN    :=
CLEV   625   375   550     0   500   550     0
GARY     0     0     0   400     0   625   375
PITT   525   525   625   600     0   625     0
;

ampl: reset data;
ampl: data multmip3a.dat;

ampl: solve;

Gurobi 7.0.0: cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6
cloudkey=0v9XdWrDQLiE3EiAAEKtFw

Capacity available on 'default' cloud pool - connecting...
Established 256-bit AES encrypted connection

Gurobi 7.0.0: optimal solution; objective 238450
163 simplex iterations
plus 33 simplex iterations for intbasis

ampl:
```

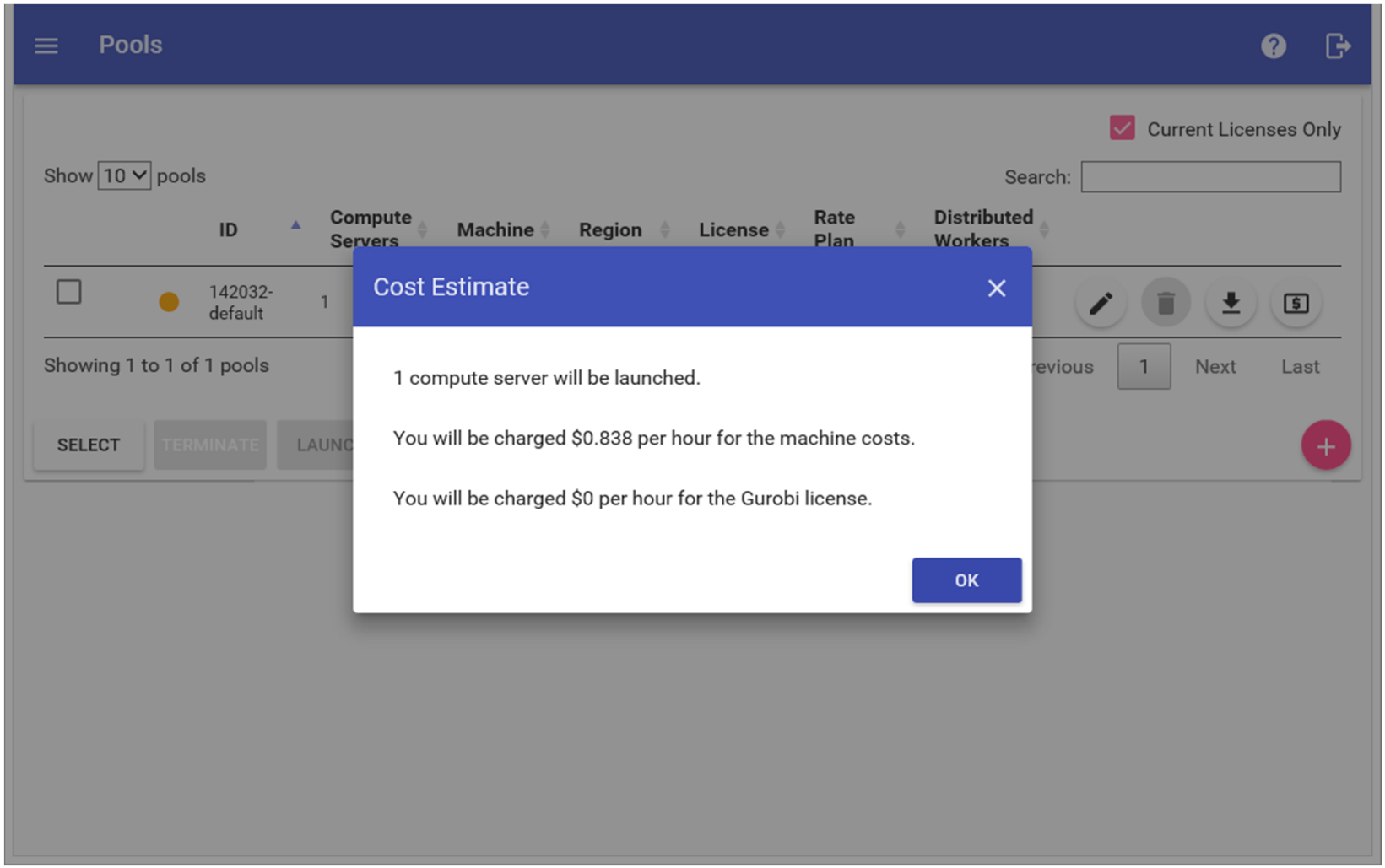
Gurobi Instant Cloud for AMPL

Manage Server Configuration



Gurobi Instant Cloud for AMPL

Check Costs



Gurobi Cloud Costs

Commercial plans

- Annual subscription fee, ***plus***
- Hourly rates for use:
  - Gurobi rate for compute servers
  - Amazon rate for distributed workers

Trials, academic use, special grants

- Amazon rate only

. . . set up through sales rep

Gurobi Cloud for AMPL: Assessment

Strengths

- Security
- Reliability (via Amazon)
- Support for multi-server and/or multi-worker pools
- Support for local modeling clients

Drawbacks (compared to NEOS)

- Not free
  - Budgeting can be complicated
- Solver-specific
- Not quite "optimization on demand"

QuanDec

Server side

- AMPL model and data
- Standard AMPL-solver installations

Client side

- Interactive tool for collaboriation & decision-making
- Runs on any recent web browser
- Java-based implementation
  - AMPL API for Java
  - Eclipse Remote Application Platform

. . . developed / supported by Cassotis Consulting

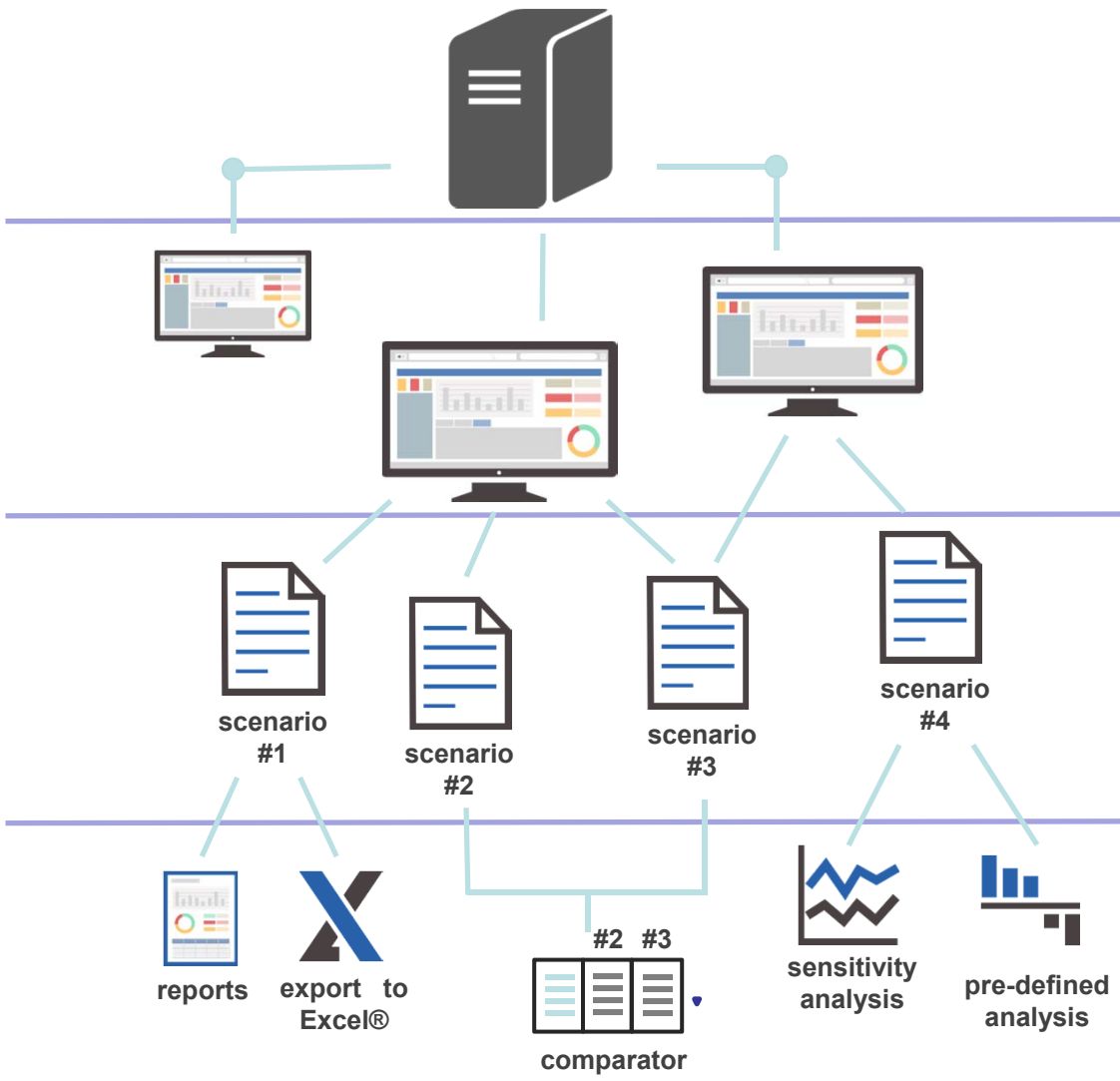
QuanΔec

The web-based graphical interface
that turns optimization models written
in AMPL into decision-making tools.

CASSOTIS
consulting

AMPL

Features



Server application

Centralized data

Several models on a single server

Web-based

Multi-users

Concurrent access

Secure access

Scenario-based

Sharing between users

Sharing rights (edit / comment / view)

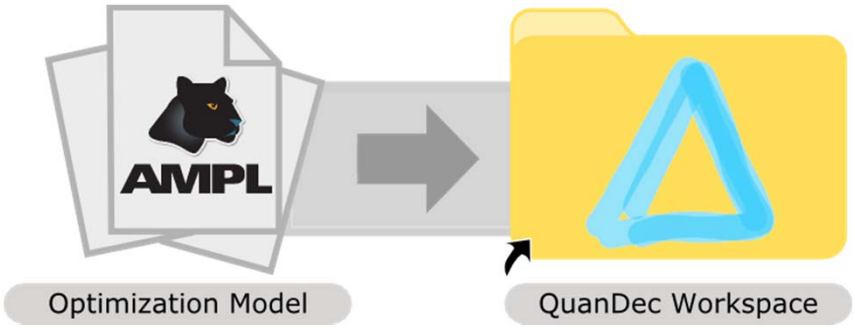
And much more…

Getting started

step 1: install QuanDec on a server

step 2: copy & paste your model files (.mod and .dat) into QuanDec's workspace

step 3: create AMPL tables and link them to QuanDec explorer

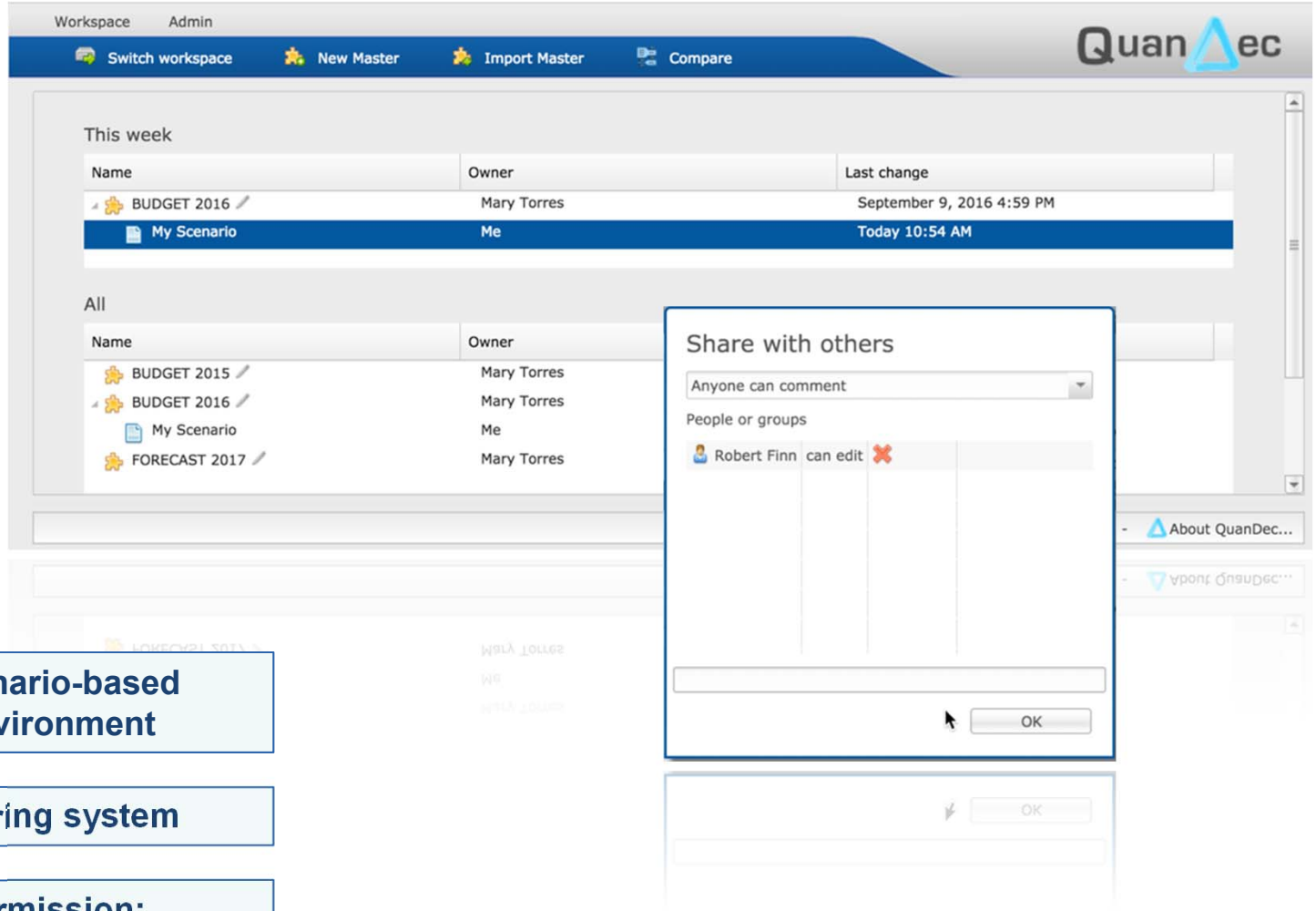


Web-application

Multi-user

Secure access

Concurrent access



Scenario-based environment

Sharing system

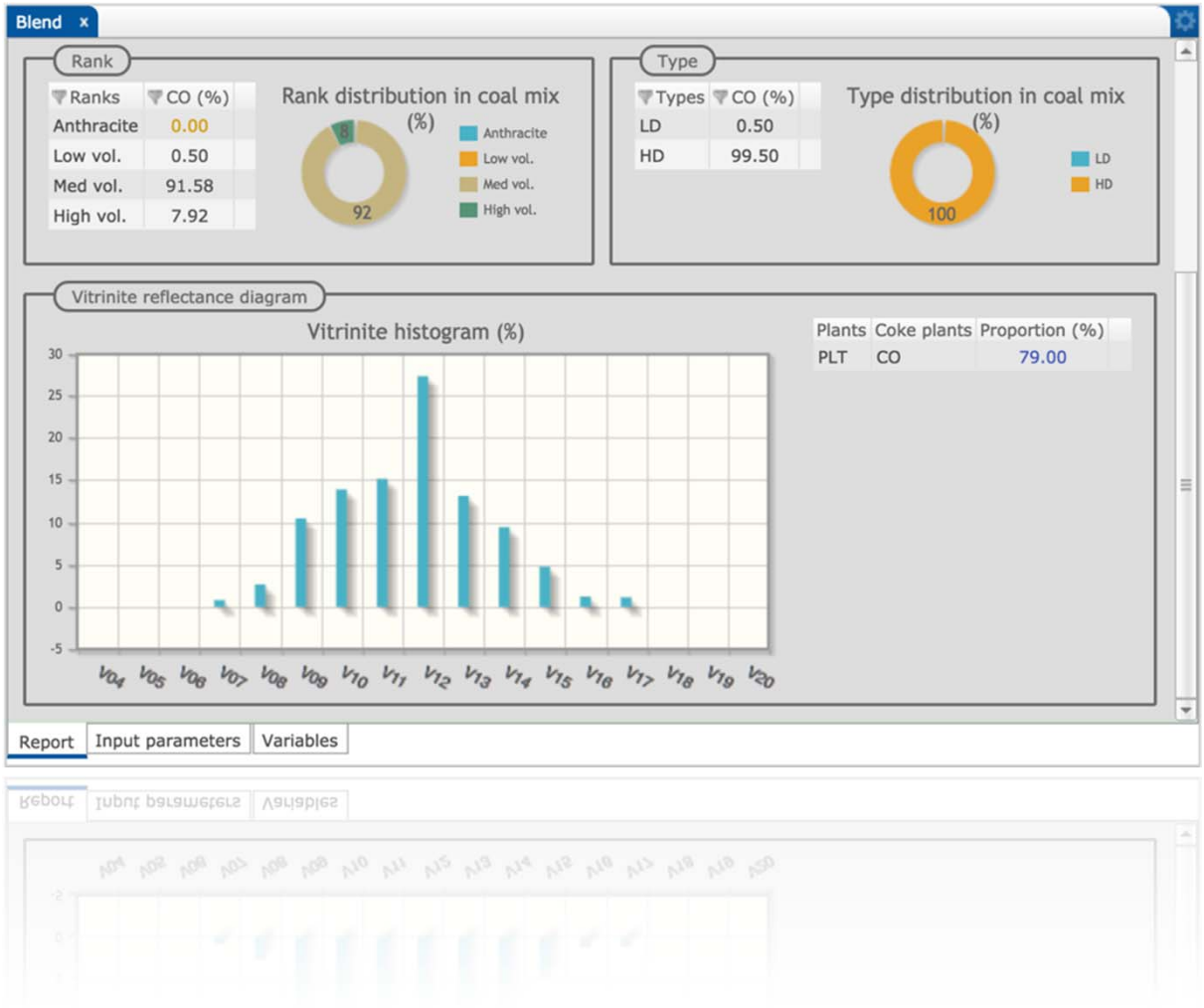
Permission:
Edit – Comment - View

3 levels:
- **Report**
- **Input parameters**
- **Variables**

Chart and tables

Colored values for easier analysis

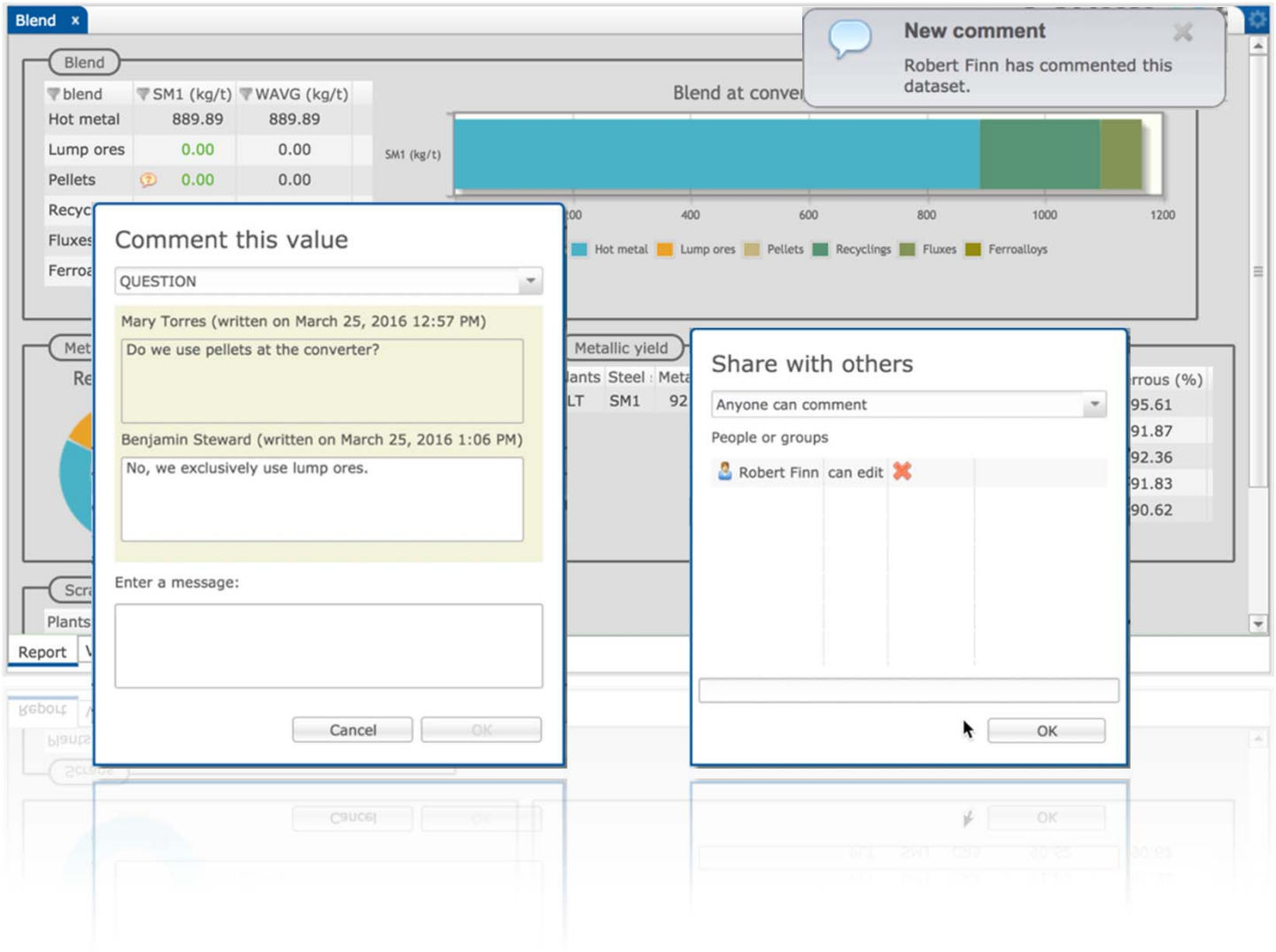
Constraint (min/max) on any variable

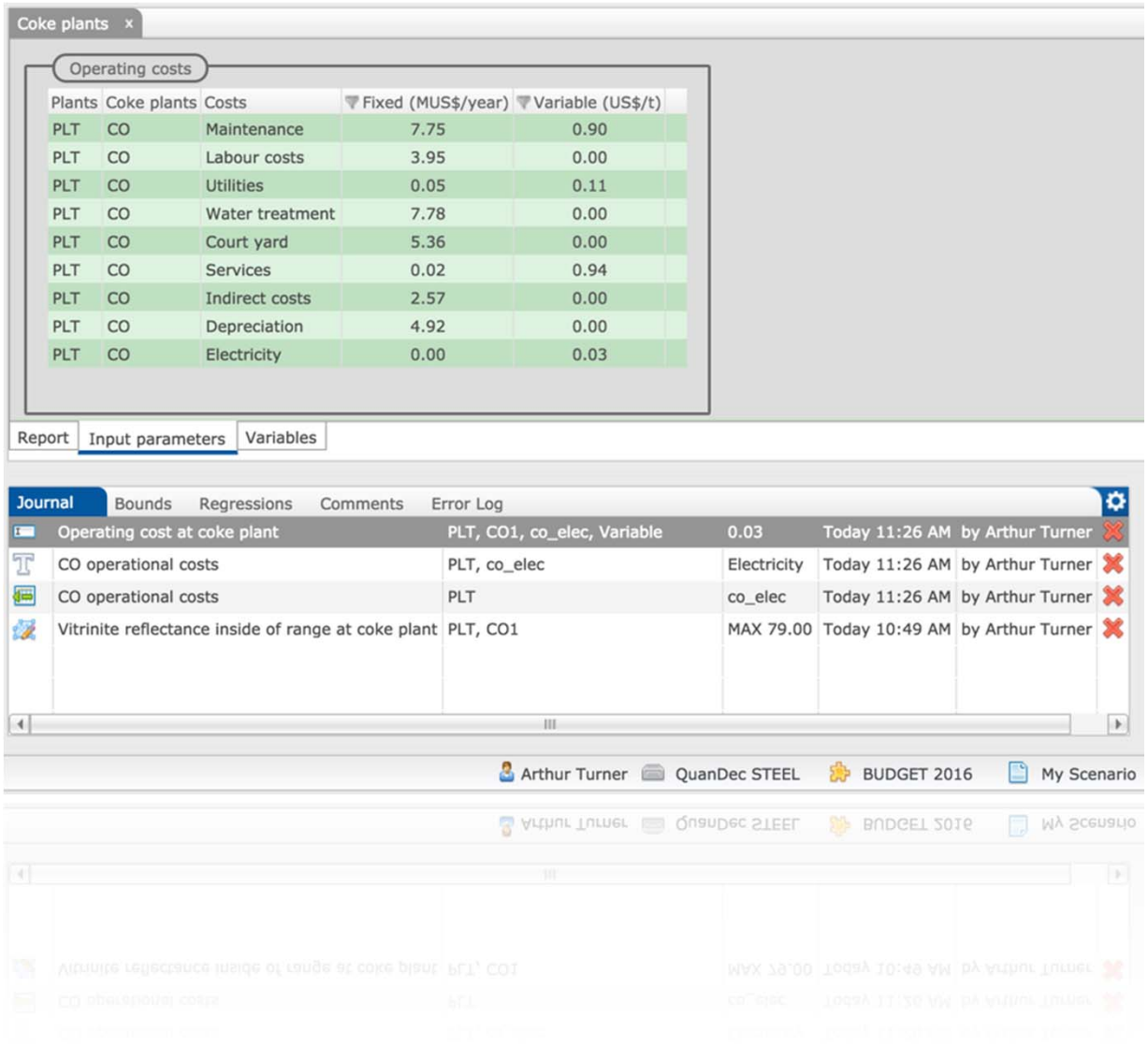


Collaborative work

Notification system

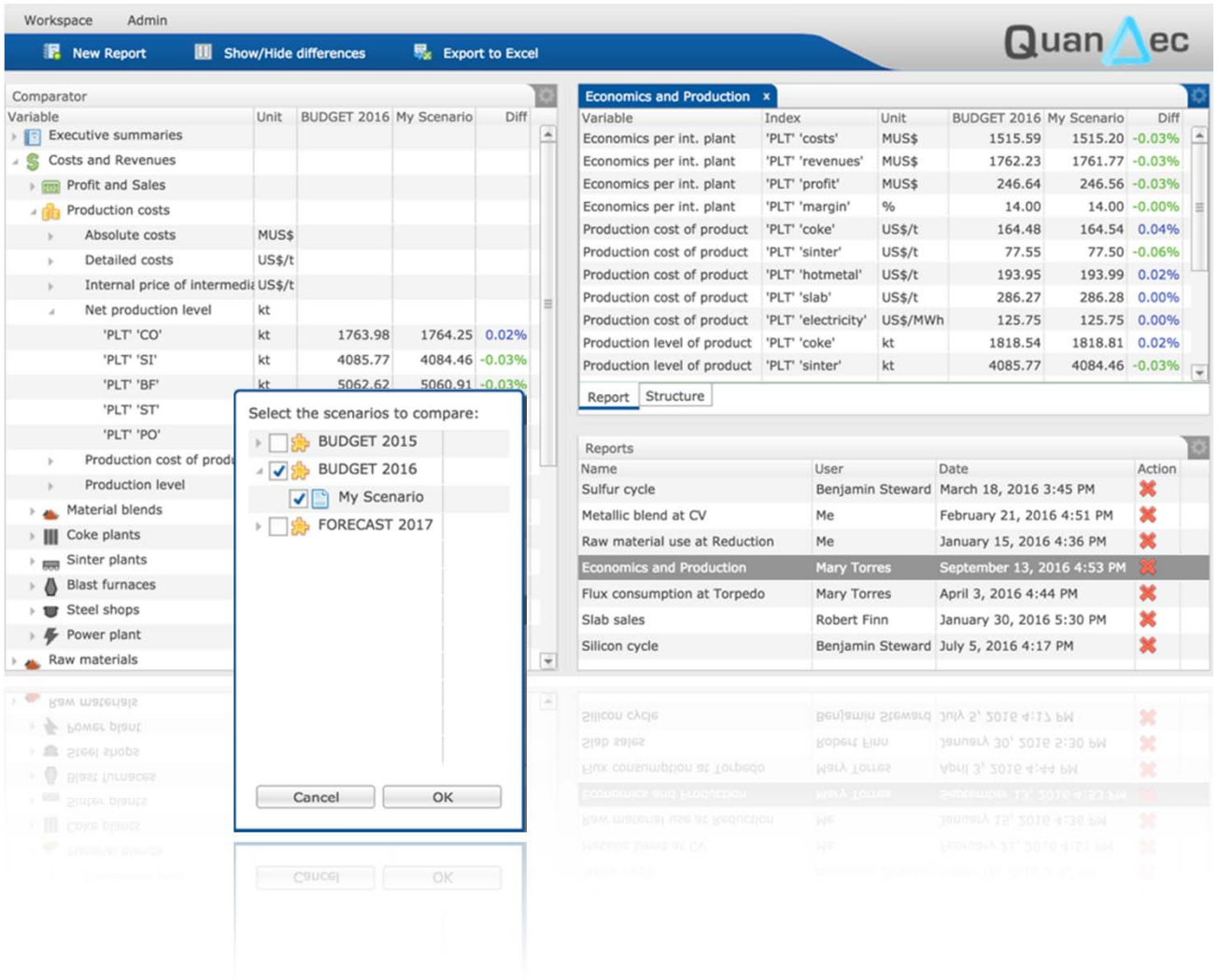
Comments between users





Scenarios with changes history

Traceability and undo system

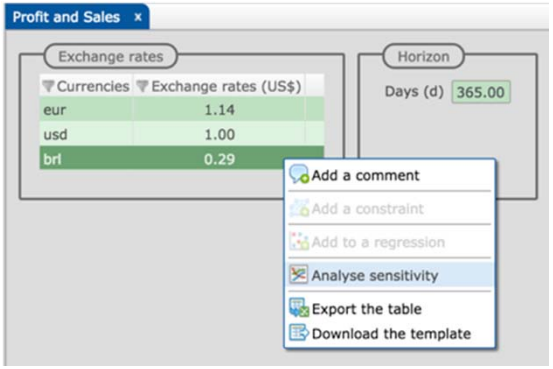


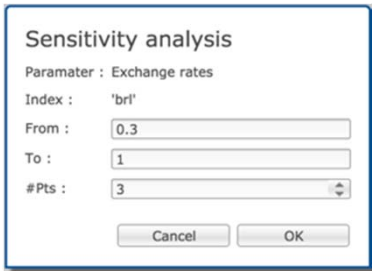
Scenarios comparison

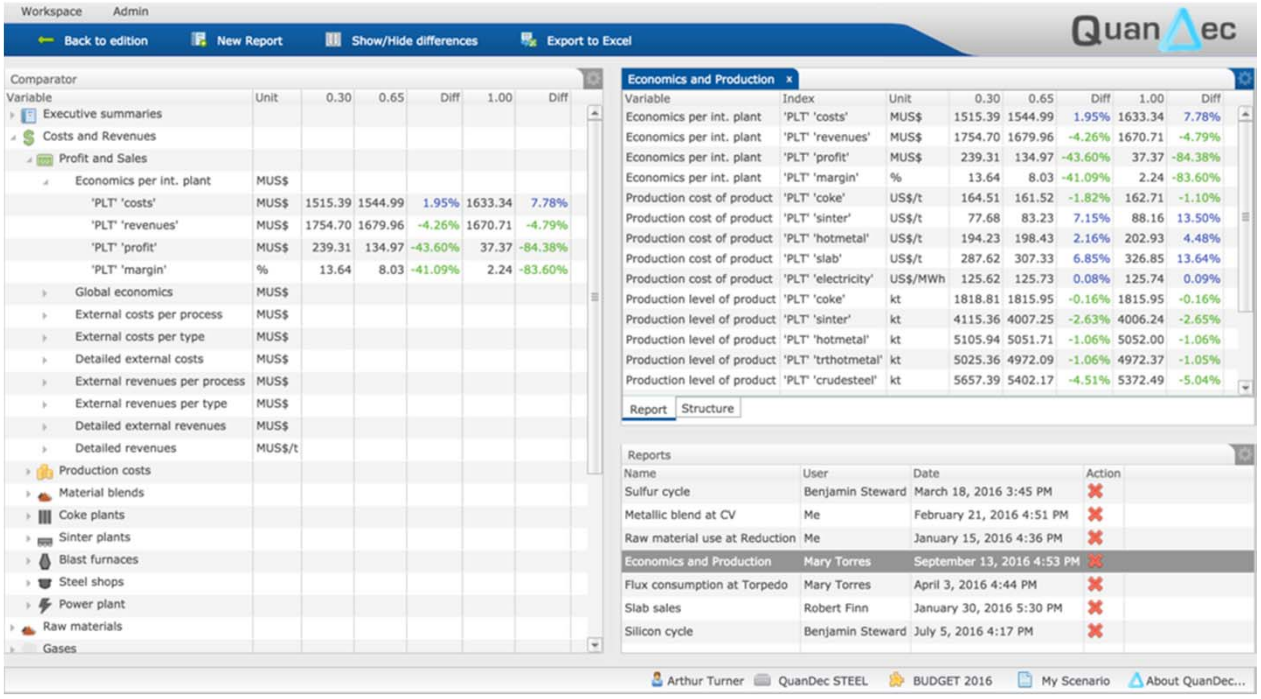
All variables can be compared

Display of relative difference

Custom reports







Sensitivity analysis

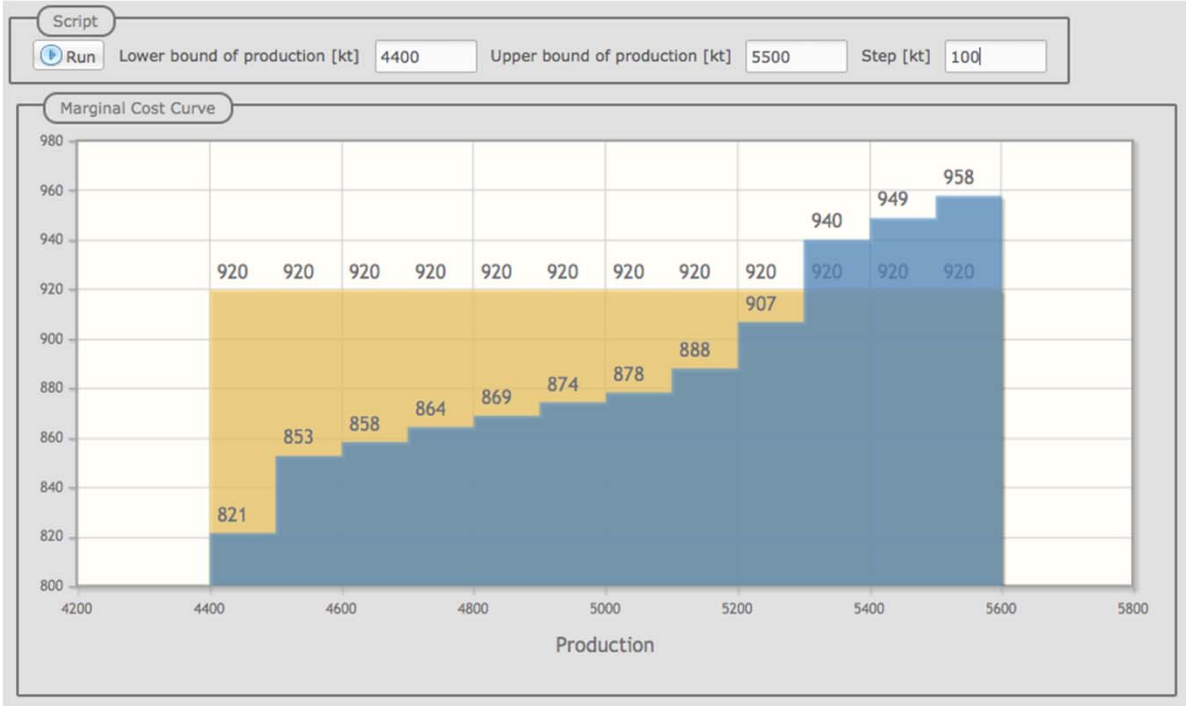
For both parameters AND variables

All variables can be compared

Display of relative difference

Predefined analyses

Script parameters



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