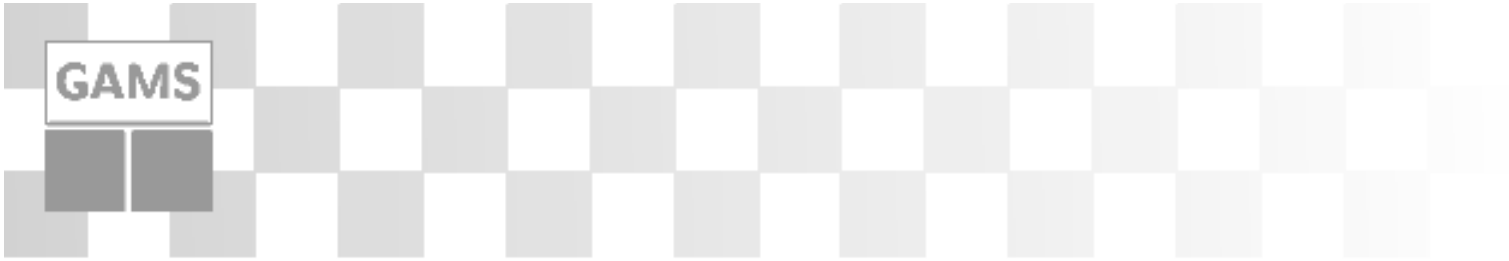

Models and Their Roles

or

A Model is a Model is a Model*

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GAMS Development Corporation

Franz Nelissen
GAMS Software GmbH

GOR Workshop "Mathematical Optimization Services in Europe"
Bad Honnef, Germany October 14-15, 2004

* Freely adapted from the poetry of Gertrude Stein, 1874-1946, American writer

Agenda

- What is GAMS
- What is a GAMS Model
- Roles of a Model
  - Communication Vehicle
  - Analytic Framework
  - Cost Saver
- Conclusions

GAMS Overview

- Started as a Research Project at the World Bank 1976
- GAMS went commercial in 1987
- Opened European Office in Cologne, Germany 1996
- 10,000s of customers in over 100 countries

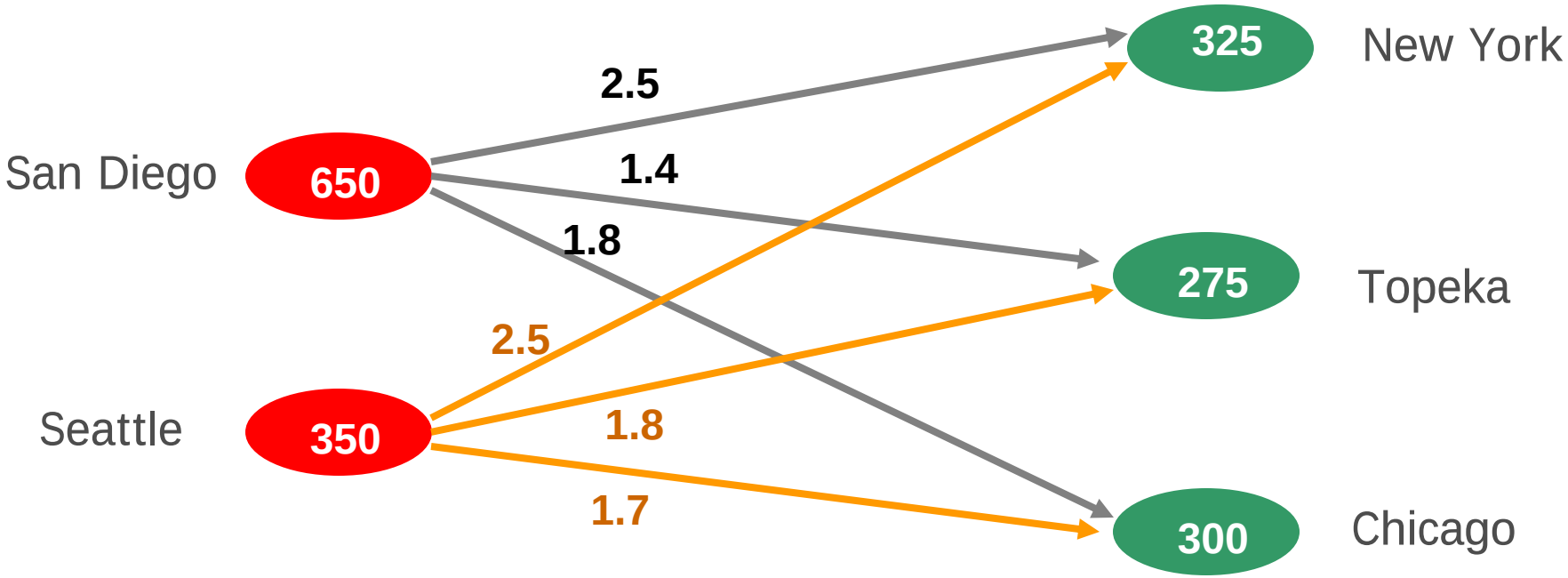
Basic Principles

- Separation of model and solution methods
- Model is a database operator and/or object
- Balanced mix of declarative and procedural approaches
- Computing platform independence
- Multiple model types, solvers, platforms

Multiple model types

- LP Linear Programming
- MIP Mixed Integer Programming
- NLP Nonlinear Programming
- MCP Mixed Complementarity Programming
- MINLP Mixed Integer Nonlinear Programming
- MPEC NLP with Complementarity Constraints
- MPSGE General Equilibrium Models
- Stochastic Optimization

Transport Example

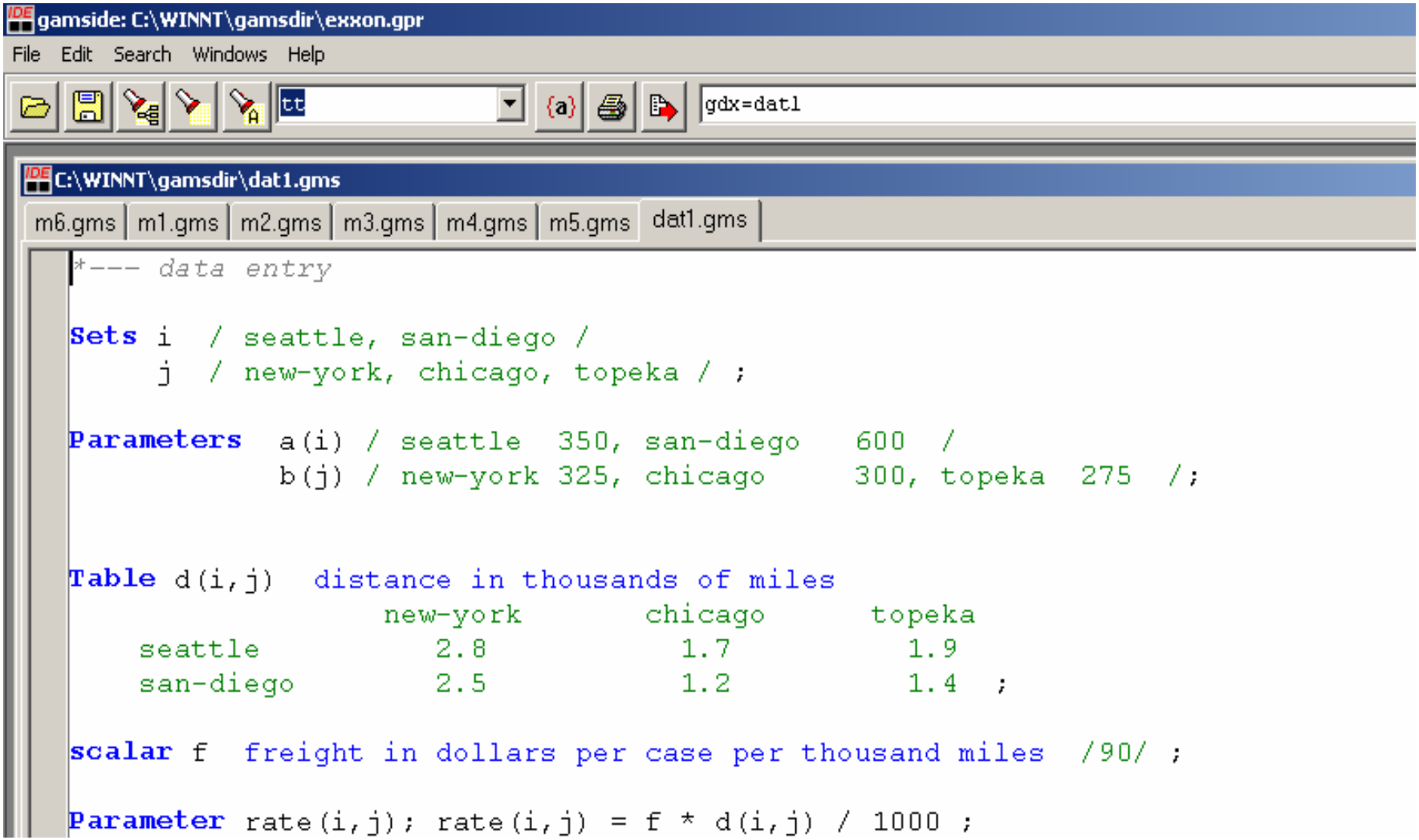


Minimize:	**Transportation cost (distance & units)**
Subject to:	**Demand satisfaction at markets**
	Supply constraints

GAMS Implementation

- Using the GAMS IDE to build a model
- Data Entry
- Max/Min Shipments
- Nonlinear Cost
- call GAMS IDE

GAMS IDE


gamside: C:\WINNT\gamsdir\exxon.gpr
File Edit Search Windows Help
tt
{a}
gdx=dat1
C:\WINNT\gamsdir\dat1.gms
m6.gms m1.gms m2.gms m3.gms m4.gms m5.gms dat1.gms
*--- data entry
Sets i / seattle, san-diego /
j / new-york, chicago, topeka / ;
Parameters a(i) / seattle 350, san-diego 600 /
b(j) / new-york 325, chicago 300, topeka 275 /;
Table d(i,j) distance in thousands of miles
new-york chicago topeka
seattle 2.8 1.7 1.9
san-diego 2.5 1.2 1.4 ;
scalar f freight in dollars per case per thousand miles /90/ ;
Parameter rate(i,j); rate(i,j) = f * d(i,j) / 1000 ;

Model m1.gms

C:\WINNT\gamsdir\m1.gms

m6.gms | m1.gms | m2.gms | m3.gms | m4.gms | m5.gms | dat1.gms

```
sets i   canning plants
     j   markets

parameters a(i)    capacity of plant i in cases
           c(i,j)  transport cost in thousands of dollars per case
           b(j)    demand at market j in cases

Variables  x(i,j)  shipment quantities in cases
           z       total transportation costs in thousands of dollars
Positive Variable x ;

Equations cost        define objective function
          supply(i)   observe supply limit at plant i
          demand(j)   satisfy demand at market j ;

cost ..        z  =e=  sum((i,j), c(i,j)*x(i,j)) ;

supply(i) ..   a(i) =g= sum(j, x(i,j)) ;

demand(j) ..   sum(i, x(i,j))  =g=  b(j);

Model m1 /all/ ;
```

Model m1.gms (cont.)

```
Model m1 /all/ ;

$call gams dat1 gdx=dat1
$gdxin dat1
$load i j a b c=rate

*--- solve LP and store results

Solve m1 us lp min z ;

parameter rep(i,j,*) Summary Report;

rep(i,j,'lp') = x.l(i,j);
```

Min/Max Shipments

```
*  min and max shipmenst
option limcol=0,limrow=0;
scalars xmin / 100 /
        xmax / 275 /;
binary variables ship(i,j)    decision variable to ship
equations        minship(i,j) minimum shipments
                 maxship(i,j) maximum shipments ;

minship(i,j).. x(i,j) =g=   xmin*ship(i,j);
maxship(i,j).. x(i,j) =l=   xmax*ship(i,j);

model m2 min shipmenst / cost,supply,demand,minship,maxship /;
solve m2 using mip minimizing z;

rep(i,j,'mip') = x.l(i,j); display rep;
```

Nonlinear Cost

```
* nonlinear cost
equation nlcost nonlinear cost function; scalar beta;

nlcost.. z =e= sum((i,j), c(i,j)*x(i,j)**beta);
model m3 / nlcost,supply,demand /;

beta = 1.5; solve m3 using nlp minimizing z;
rep(i,j,'nlp-convex') = x.l(i,j);

beta = 0.6; solve m3 using nlp minimizing z;
rep(i,j,'nlp-non') = x.l(i,j);

option nlp=baron; solve m3 using nlp minimizing z;
rep(i,j,'nlp-baron') = x.l(i,j); display rep;
```

Min/Max and NL objective

```
* min/max and nl obj

model m4 / nlcost,supply,demand, minship,maxship /;

option minlp=baron; solve m4 using minlp minimizing z;
option nlp=snopt;          option optcr=0;
option minlp=sbb; solve m4 using minlp minimizing z;

rep(i,j,'minlp') = x.l(i,j); display rep;
```

What is a Model?

- List of Equations
  - *Mathematical Programming (MP) Model*
- Collection of several intertwined (MP) Models
  - Data Preparation and Calibration
  - "*Solution*" Module
  - Reporting Module
- Categorization of Models by answering:
  - Who is the *User* of a Model?

We are not Consultants

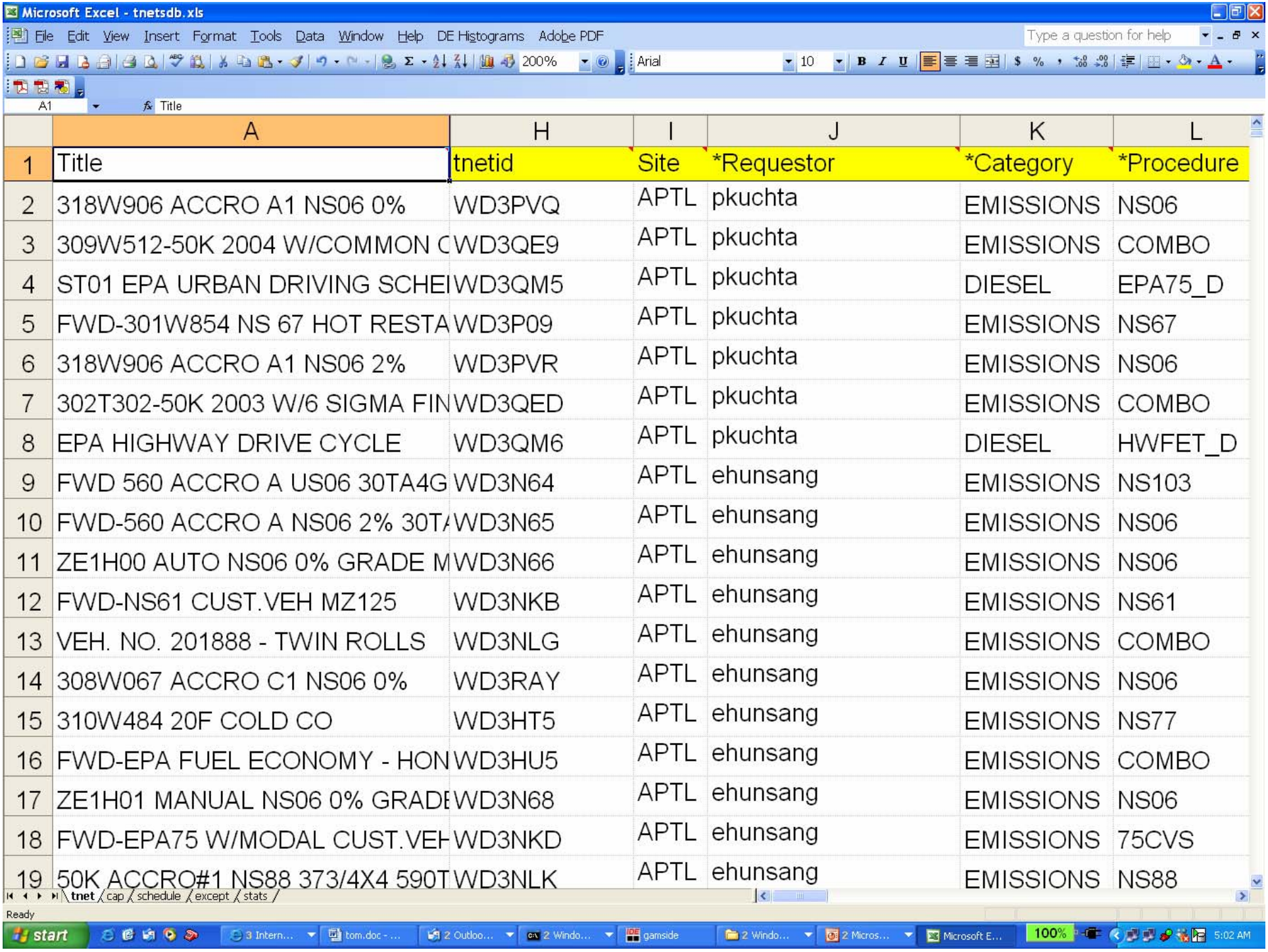
- No active acquisition of projects
- Extended User Support
- Projects with long time “friends”
- Help our clients out, if they are in “trouble”

Communication Vehicle

- Defining scope of a (part of a) project/model
- IT, analysts, managers, model builders have different views
- Misunderstandings common with verbal descriptions
- Use a model to define the scope
- Requirements for such a model
  - Rapid prototyping (max. 1-2 man days)
  - Standard IO interface (Excel)
  - Remote execution (Model Server)

Example

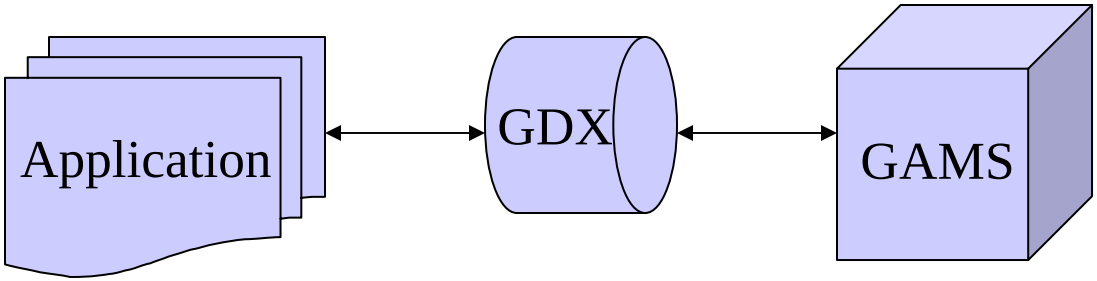
- Project in 2002 with large automotive company, scheduling of design verifications (tests)
- Replacement of I2 “off-the-shelf” scheduling tool, with customized model
- Scope defining model prototype
  - Built during first project meeting (<300 LOC)
  - Required data and output reports in spreadsheet
  - Model execution via email based GAMS remote application server (GRAS)



	A	H	I	J	K	L
1	Title	tnetid	Site	*Requestor	*Category	*Procedure
2	318W906 ACCRO A1 NS06 0%	WD3PVQ	APTL	pkuchta	EMISSIONS	NS06
3	309W512-50K 2004 W/COMMON C	WD3QE9	APTL	pkuchta	EMISSIONS	COMBO
4	ST01 EPA URBAN DRIVING SCHEI	WD3QM5	APTL	pkuchta	DIESEL	EPA75_D
5	FWD-301W854 NS 67 HOT RESTA	WD3P09	APTL	pkuchta	EMISSIONS	NS67
6	318W906 ACCRO A1 NS06 2%	WD3PVR	APTL	pkuchta	EMISSIONS	NS06
7	302T302-50K 2003 W/6 SIGMA FIN	WD3QED	APTL	pkuchta	EMISSIONS	COMBO
8	EPA HIGHWAY DRIVE CYCLE	WD3QM6	APTL	pkuchta	DIESEL	HWFET_D
9	FWD 560 ACCRO A US06 30TA4G	WD3N64	APTL	ehunsang	EMISSIONS	NS103
10	FWD-560 ACCRO A NS06 2% 30T/	WD3N65	APTL	ehunsang	EMISSIONS	NS06
11	ZE1H00 AUTO NS06 0% GRADE M	WD3N66	APTL	ehunsang	EMISSIONS	NS06
12	FWD-NS61 CUST.VEH MZ125	WD3NKB	APTL	ehunsang	EMISSIONS	NS61
13	VEH. NO. 201888 - TWIN ROLLS	WD3NLG	APTL	ehunsang	EMISSIONS	COMBO
14	308W067 ACCRO C1 NS06 0%	WD3RAY	APTL	ehunsang	EMISSIONS	NS06
15	310W484 20F COLD CO	WD3HT5	APTL	ehunsang	EMISSIONS	NS77
16	FWD-EPA FUEL ECONOMY - HON	WD3HU5	APTL	ehunsang	EMISSIONS	COMBO
17	ZE1H01 MANUAL NS06 0% GRADE	WD3N68	APTL	ehunsang	EMISSIONS	NS06
18	FWD-EPA75 W/MODAL CUST.VEH	WD3NKD	APTL	ehunsang	EMISSIONS	75CVS
19	50K ACCRO#1 NS88 373/4X4 590T	WD3NLK	APTL	ehunsang	EMISSIONS	NS88

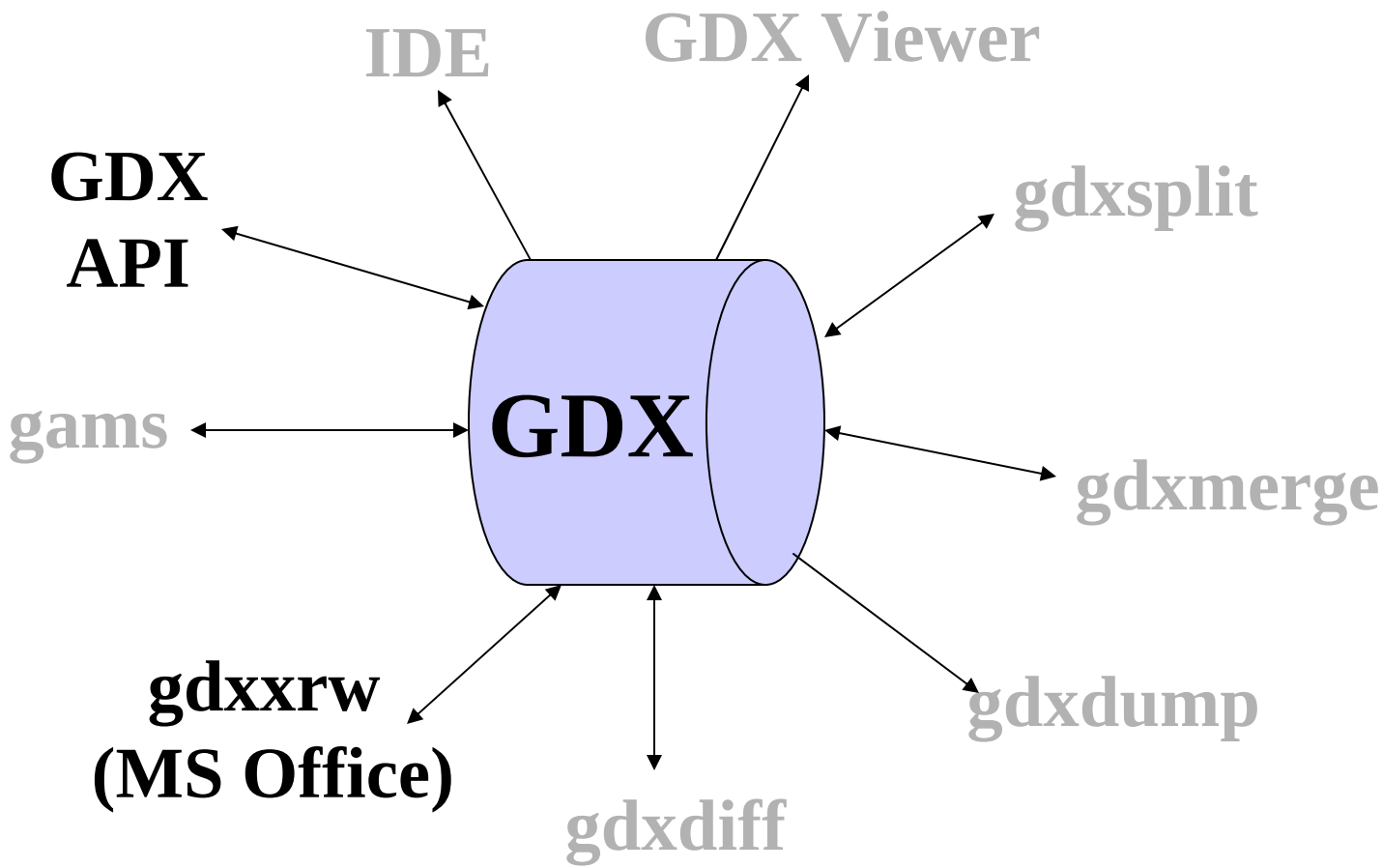
Gams Data eXchange

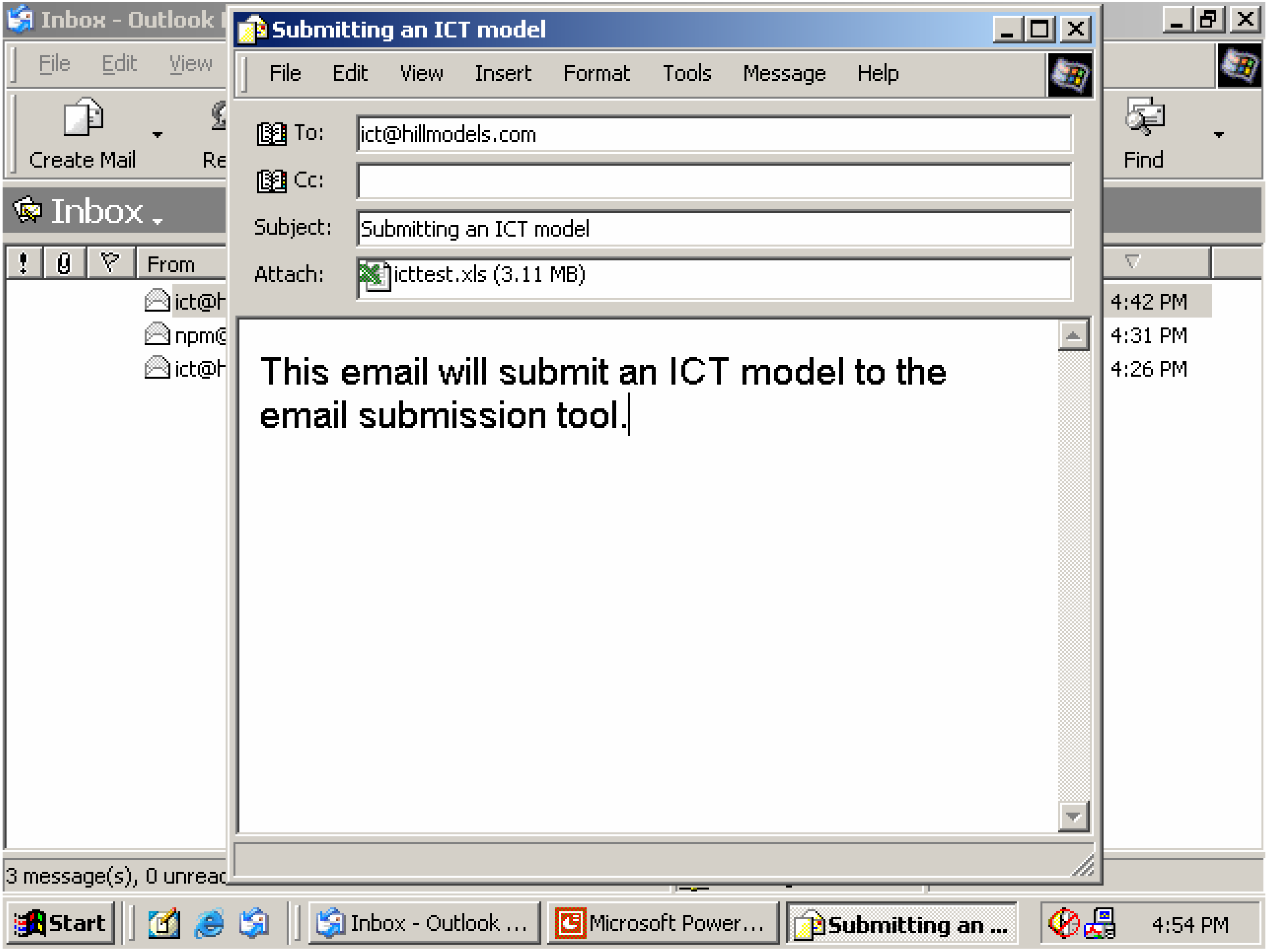
- Gams Data eXchange (GDX):

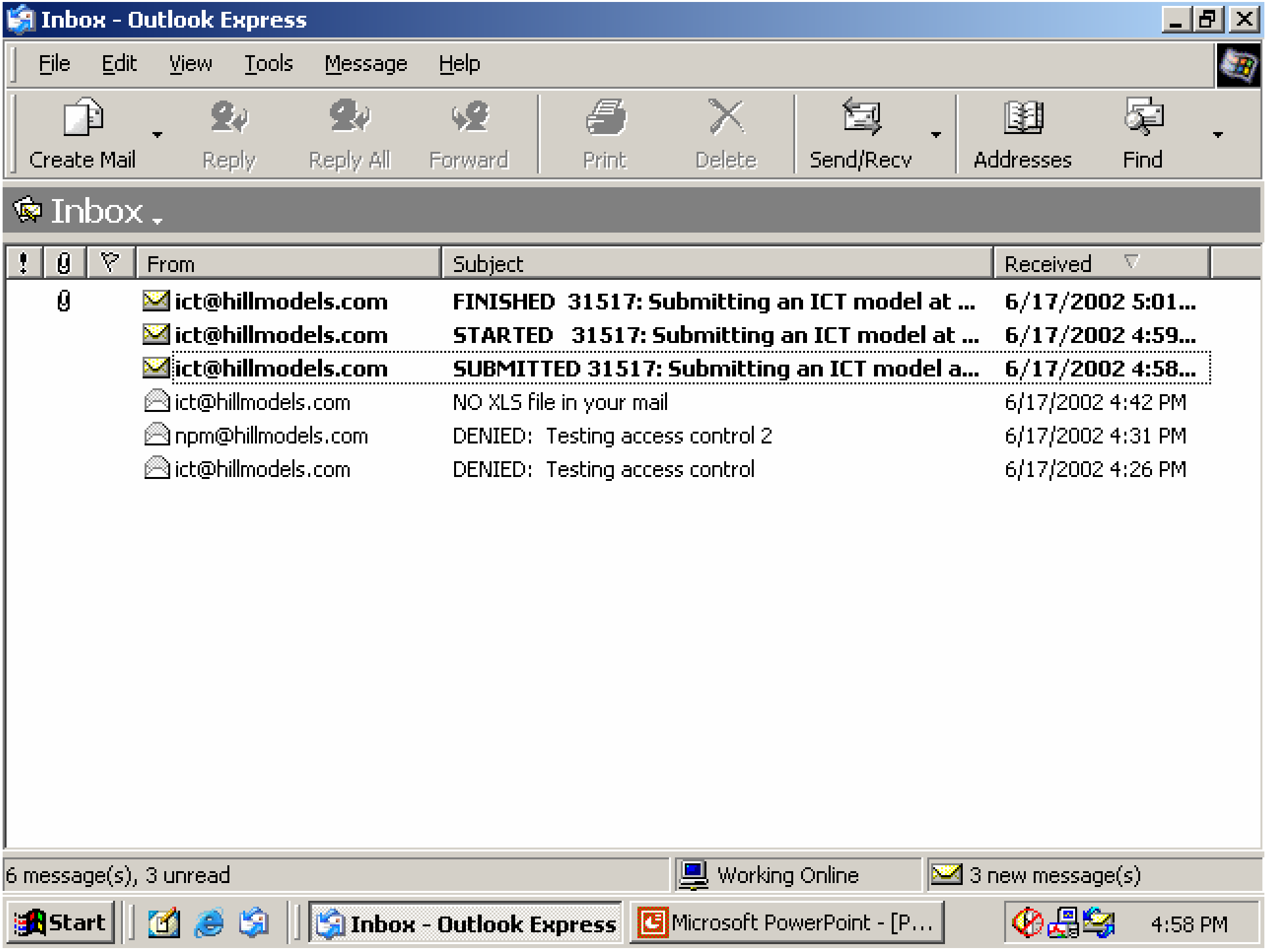


- Complements the ASCII text data input
- Advantages:
  - Fast exchange of data
  - Syntactical check on data before model starts
  - Compile-time and Run-time Data Exchange

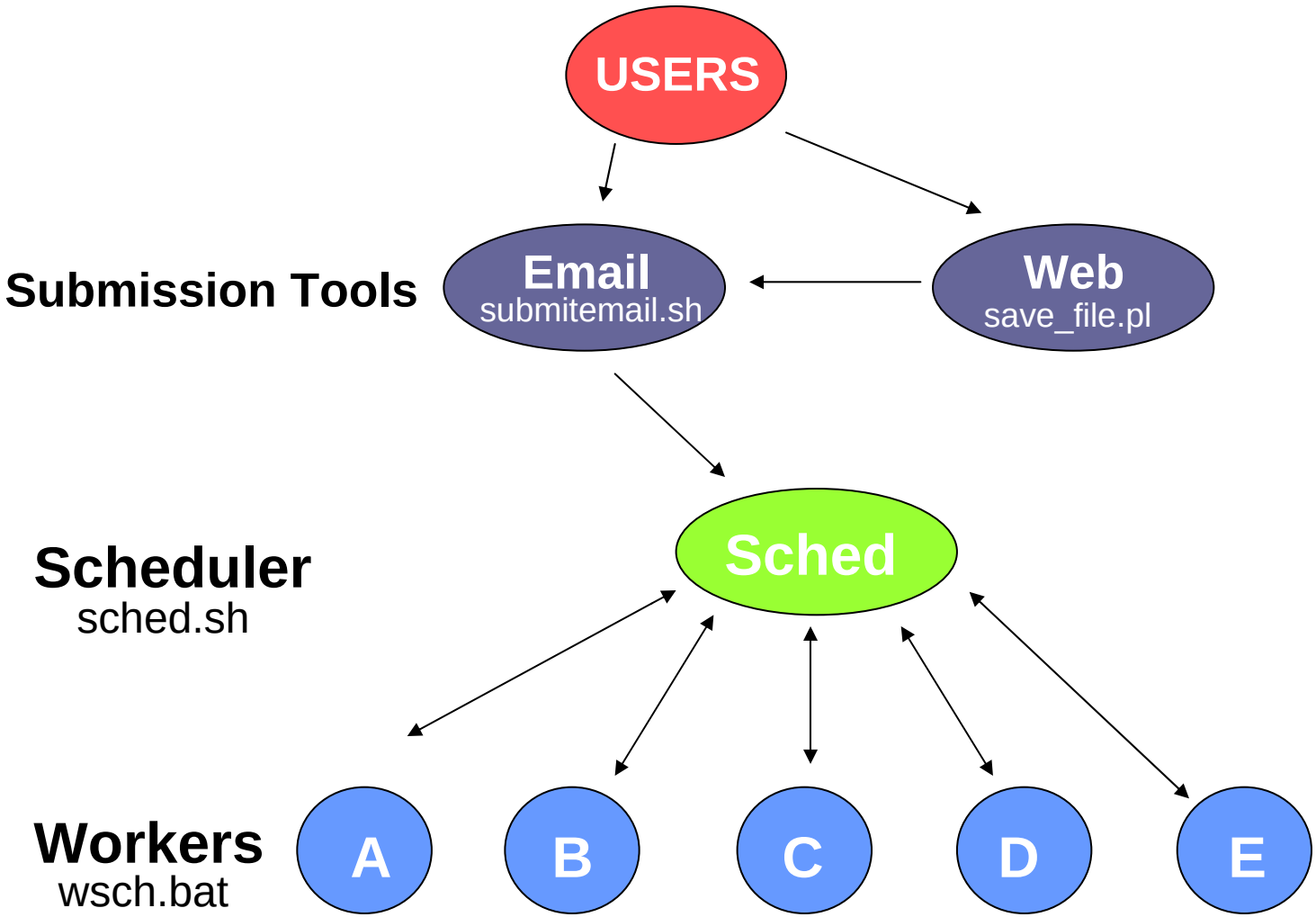
GDX Tools


IDE
GDX Viewer
GDX API
gdxsplit
gams
GDX
gdxmerge
gdxxrw (MS Office)
gdxdump
gdxdiff


Inbox - Outlook
File Edit View
Create Mail
Find
Inbox
From
ict@h
npm@
ict@h
4:42 PM
4:31 PM
4:26 PM
3 message(s), 0 unread
Submitting an ICT model
File Edit View Insert Format Tools Message Help
To: ict@hillmodels.com
Cc:
Subject: Submitting an ICT model
Attach: icttest.xls (3.11 MB)
This email will submit an ICT model to the email submission tool.
Start
Inbox - Outlook ...
Microsoft Power...
Submitting an ...
4:54 PM


Inbox - Outlook Express
File Edit View Tools Message Help
Create Mail
Reply
Reply All
Forward
Print
Delete
Send/Recv
Addresses
Find
Inbox
From
Subject
Received
ict@hillmodels.com
FINISHED 31517: Submitting an ICT model at ...
6/17/2002 5:01...
ict@hillmodels.com
STARTED 31517: Submitting an ICT model at ...
6/17/2002 4:59...
ict@hillmodels.com
SUBMITTED 31517: Submitting an ICT model a...
6/17/2002 4:58...
ict@hillmodels.com
NO XLS file in your mail
6/17/2002 4:42 PM
npm@hillmodels.com
DENIED: Testing access control 2
6/17/2002 4:31 PM
ict@hillmodels.com
DENIED: Testing access control
6/17/2002 4:26 PM
6 message(s), 3 unread
Working Online
3 new message(s)
Start
Inbox - Outlook Express
Microsoft PowerPoint - [P...
4:58 PM

GRAS Architecture



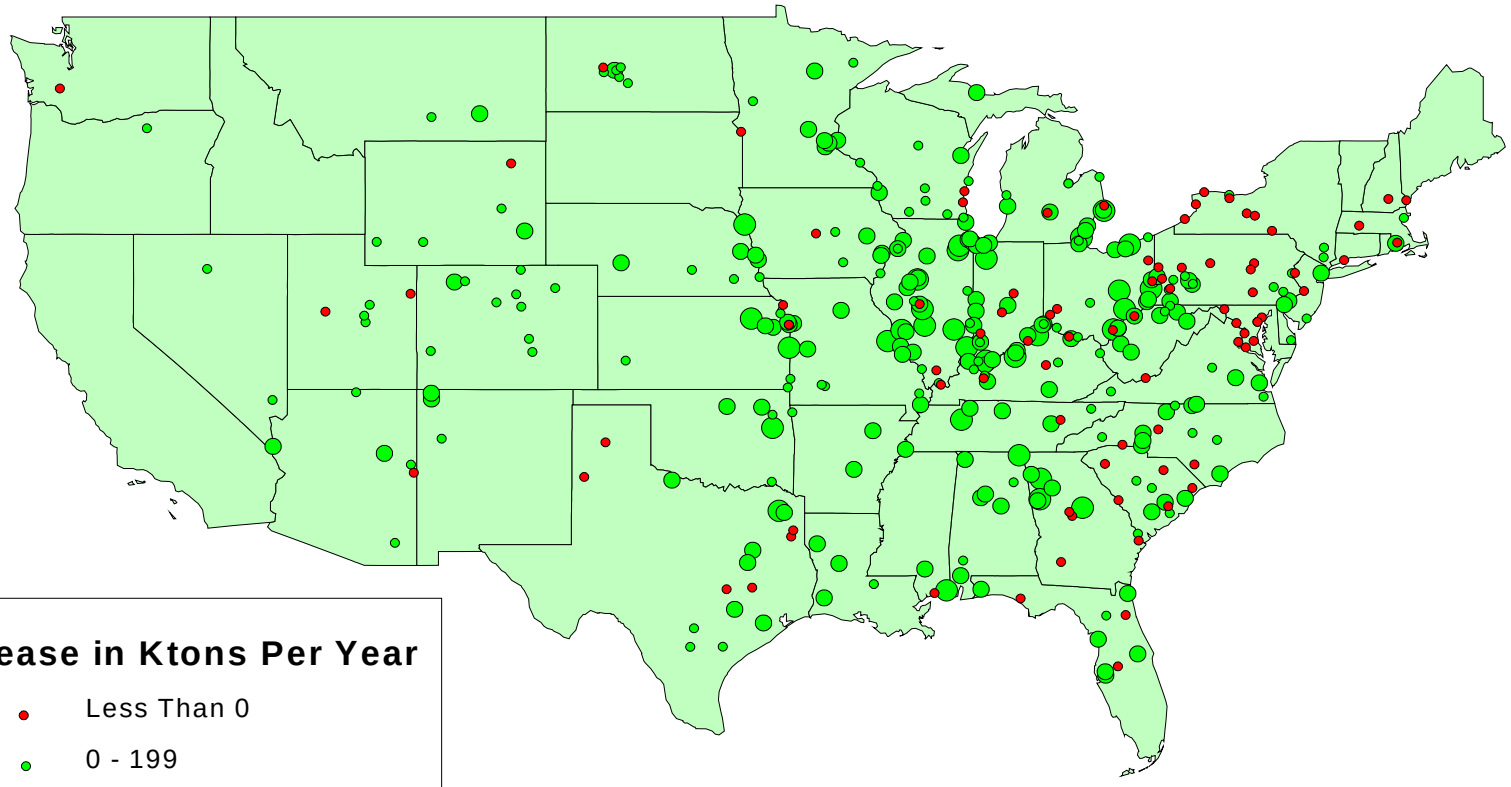
Analytic Framework

- Optimization models do not allow for any type of vagueness
  - Input data requirements
  - Objectives and constraints
  - Results
- Misunderstandings result in failure of the model
  - Compilation/execution errors
  - Infeasible/unbounded MP models
- Model as a contract

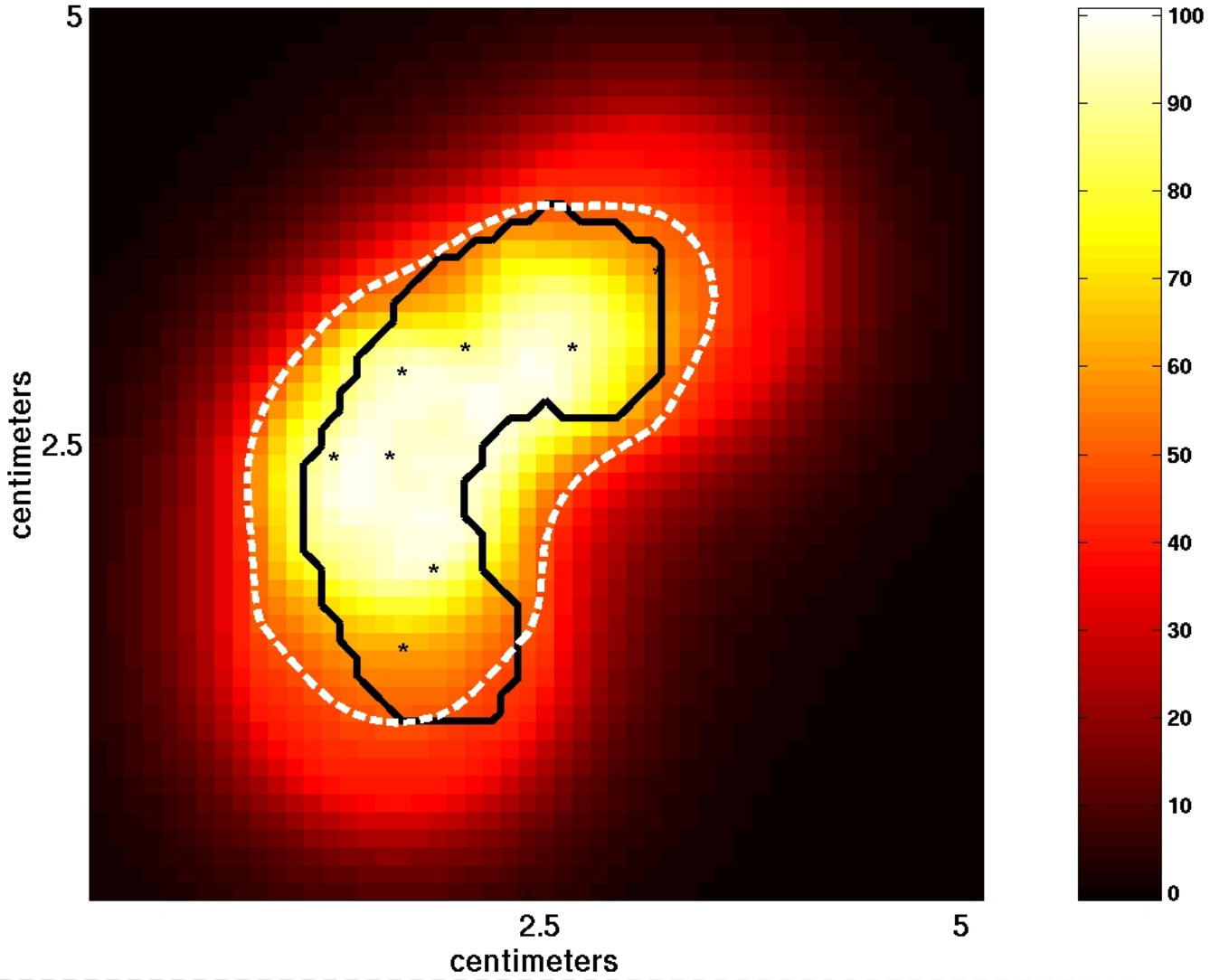
Model as a Contract

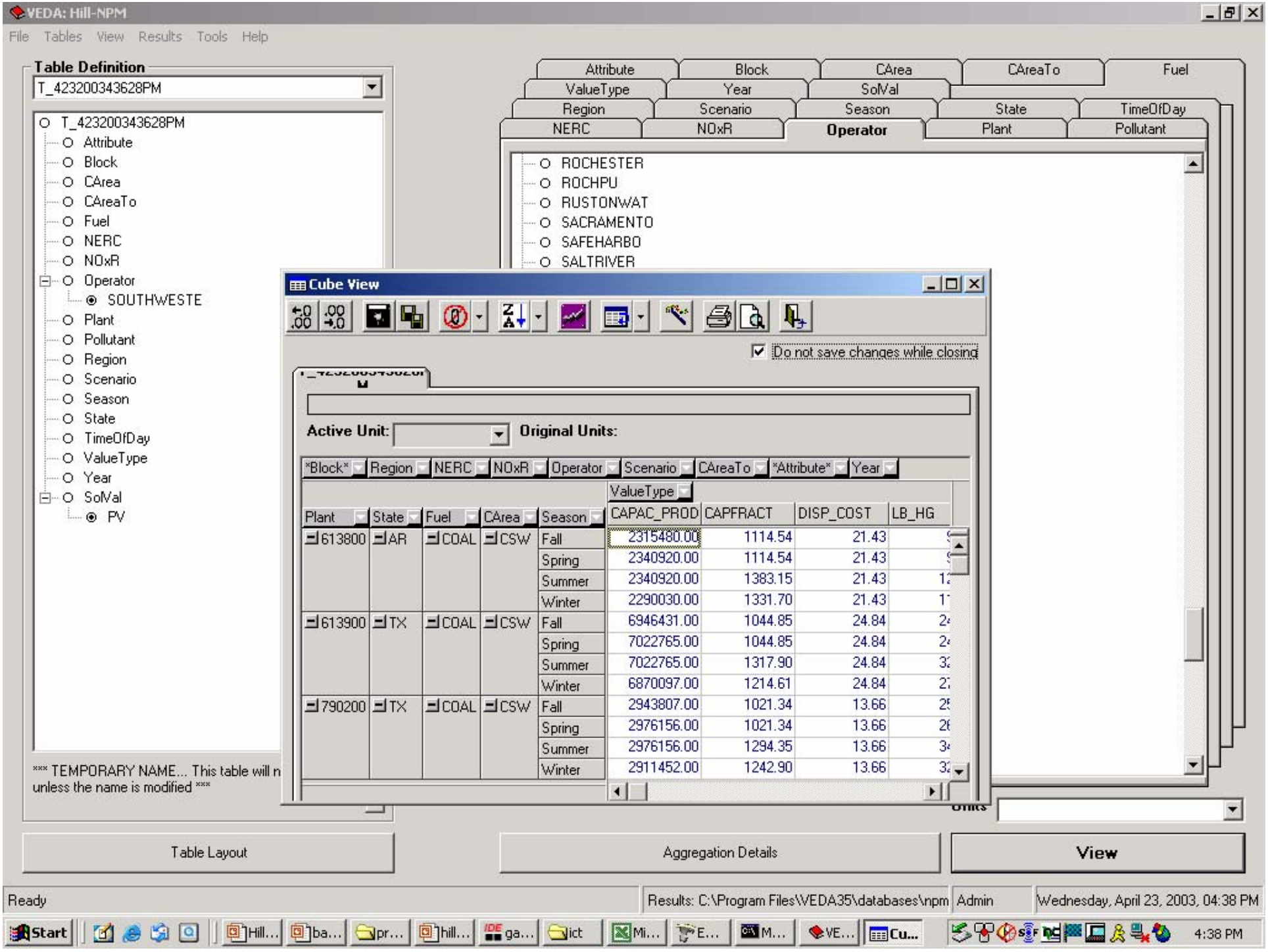
- Good models do not rely on contract (input data)
- Input Module (handles bad data)
  - Simple error checks
  - Analyzing and reporting complex data problems
- Good models (modeling systems) provide access to results via independent *result analyzers* for non model experts
- Analytic framework help define *result metric*
  - e.g. violations of soft constraints

GAMS/MapInfo



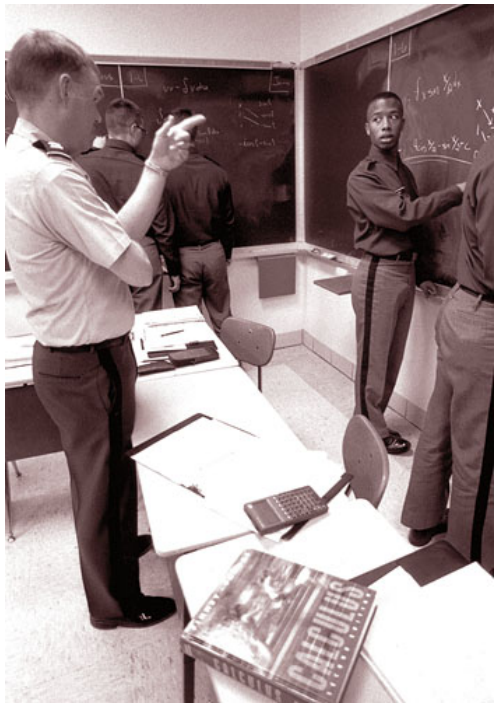
GAMS/MATLAB

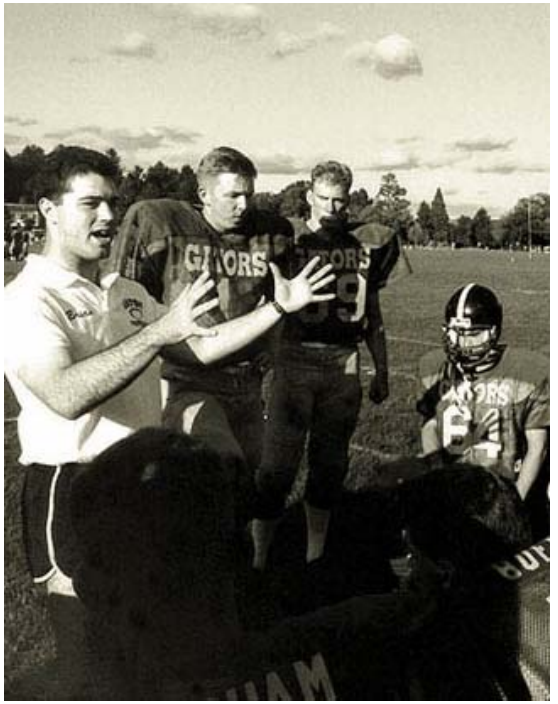

5
2.5
centimeters
2.5
5
centimeters
100
90
80
70
60
50
40
30
20
10
0


VEDA: Hill-NPM
File Tables View Results Tools Help
Table Definition
T_423200343628PM
T_423200343628PM
Attribute
Block
CArea
CAreaTo
Fuel
NERC
NOxR
Operator
Plant
Pollutant
Region
Scenario
Season
State
TimeOfDay
ValueType
Year
SolVal
PV
SOUTHWESTE
*** TEMPORARY NAME... This table will n
unless the name is modified ***
Attribute
Block
CArea
CAreaTo
Fuel
ValueType
Year
SolVal
Region
Scenario
Season
State
TimeOfDay
NERC
NOxR
Operator
Plant
Pollutant
ROCHESTER
ROCHPU
RUSTONWAT
SACRAMENTO
SAFEHARBO
SALTRIVER
Cube View
Do not save changes while closing
Active Unit:
Original Units:
Block
Region
NERC
NOxR
Operator
Scenario
CAreaTo
Attribute
Year
ValueType
Plant
State
Fuel
CArea
Season
CAPAC_PROD
CAPFRACT
DISP_COST
LB_HG
613800 AR COAL CSW Fall 2315480.00 1114.54 21.43
Spring 2340920.00 1114.54 21.43
Summer 2340920.00 1383.15 21.43
Winter 2290030.00 1331.70 21.43
613900 TX COAL CSW Fall 6946431.00 1044.85 24.84
Spring 7022765.00 1044.85 24.84
Summer 7022765.00 1317.90 24.84
Winter 6870097.00 1214.61 24.84
790200 TX COAL CSW Fall 2943807.00 1021.34 13.66
Spring 2976156.00 1021.34 13.66
Summer 2976156.00 1294.35 13.66
Winter 2911452.00 1242.90 13.66
Table Layout
Aggregation Details
View
Ready
Results: C:\Program Files\VEDA35\databases\npm
Admin
Wednesday, April 23, 2003, 04:38 PM
Start
4:38 PM

Scheduling US Military Academy West Point

" … each student's daily activities are a carefully regimented balance of academic, military, and physical requirements."





An Optimization Model

$$\min \sum_{ro}(p1_{ro} * \pi 1_{ro} + p2_{ro} * \pi 2_{ro}) + \sum_{c}(p3_c * \pi 3_c + p4_c * \pi 4_c)$$

$$\sum_{o} x_{c,ro} = 1 \qquad \text{(for all 8TAP entries)}$$

$$\sum_{r} x_{c,ro} \leq 1 + \pi 3_c \qquad \text{(for all cadets } c \text{ for all time slots } o\text{)}$$

$$-\sigma - \pi 4_c \leq \sum_{ro \text{ on day-1}} x_{c,ro} - \sum_{ro \text{ on day-2}} x_{c,ro} \leq \sigma + \pi 4_c \qquad \text{(for all cadets } c\text{)}$$

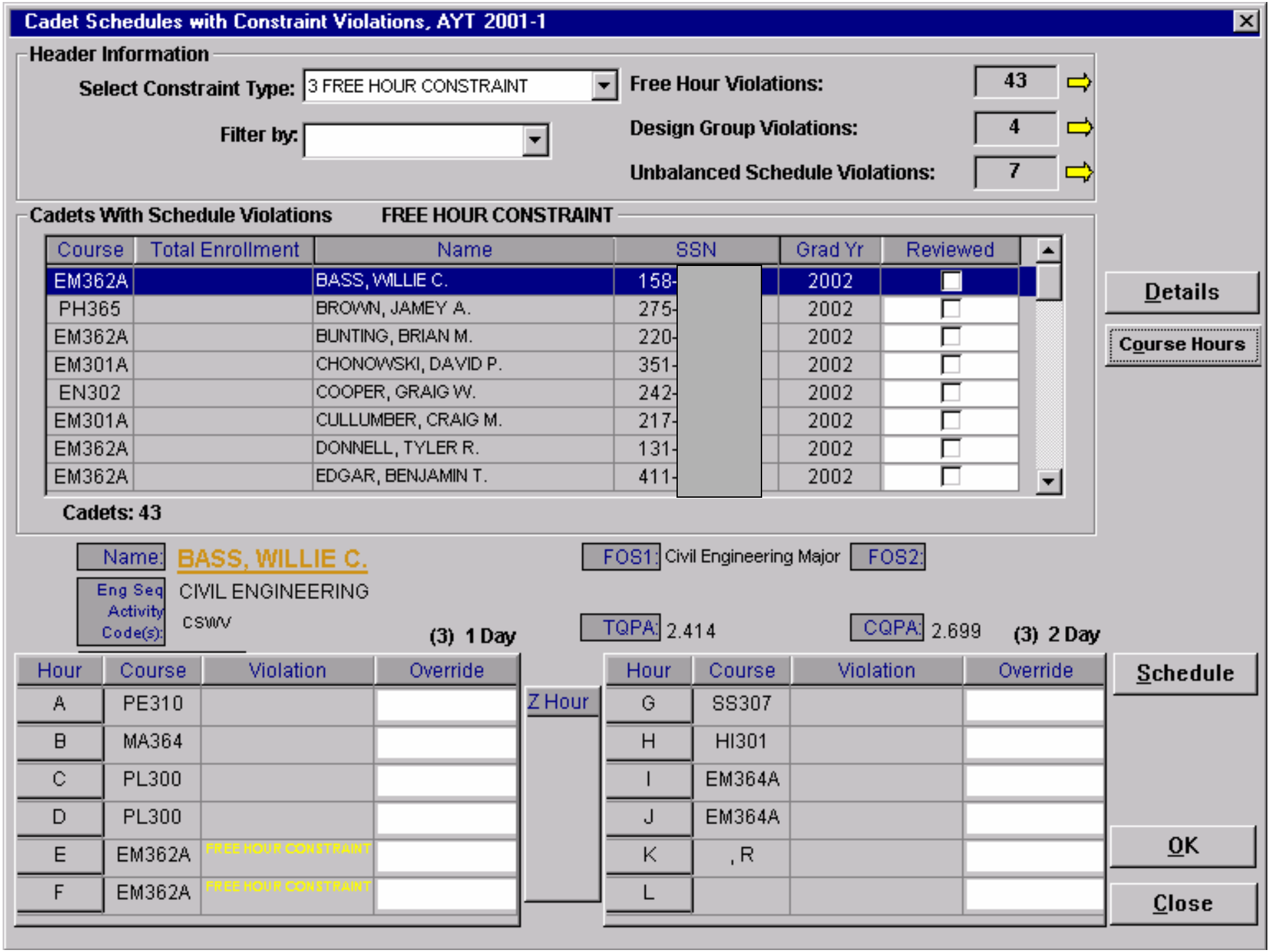
$$x_{c,ro} = 0 \qquad \text{(for all } c, ro \text{ where } c \text{ has activity at } o\text{)}$$

$$\sum_{c} x_{c,ro} \leq cap_{ro} + \pi 1_{ro} \qquad \text{(for all course hours } ro\text{)}$$

$$\sum_{c \text{ freshman\&athlete}} x_{c,ro} - 0.6 \sum_{c} x_{c,ro} \leq \pi 2_{ro} \qquad \text{(for all course hours } ro\text{)}$$

Pre-Scheduling

- One cadet at a time
- Thousands of small MIPs
- If infeasible produce several infeasible schedules
- Human accepts infeasible schedule or modifies data


Cadet Schedules with Constraint Violations, AYT 2001-1
Header Information
Select Constraint Type: 3 FREE HOUR CONSTRAINT
Filter by:
Free Hour Violations: 43
Design Group Violations: 4
Unbalanced Schedule Violations: 7
Cadets With Schedule Violations FREE HOUR CONSTRAINT
Course | Total Enrollment | Name | SSN | Grad Yr | Reviewed
EM362A | BASS, WILLIE C. | 158- | 2002
PH365 | BROWN, JAMEY A. | 275- | 2002
EM362A | BUNTING, BRIAN M. | 220- | 2002
EM301A | CHONOWSKI, DAVID P. | 351- | 2002
EN302 | COOPER, GRAIG W. | 242- | 2002
EM301A | CULLUMBER, CRAIG M. | 217- | 2002
EM362A | DONNELL, TYLER R. | 131- | 2002
EM362A | EDGAR, BENJAMIN T. | 411- | 2002
Cadets: 43
Details
Course Hours
Name: BASS, WILLIE C.
FOS1: Civil Engineering Major
FOS2:
Eng Seq Activity Code(s): CIVIL ENGINEERING CSWV
TQPA: 2.414
CQPA: 2.699
(3) 1 Day
(3) 2 Day
Hour | Course | Violation | Override
A | PE310
B | MA364
C | PL300
D | PL300
E | EM362A | FREE HOUR CONSTRAINT
F | EM362A | FREE HOUR CONSTRAINT
Z Hour
Hour | Course | Violation | Override
G | SS307
H | HI301
I | EM364A
J | EM364A
K | , R
L
Schedule
OK
Close

Results

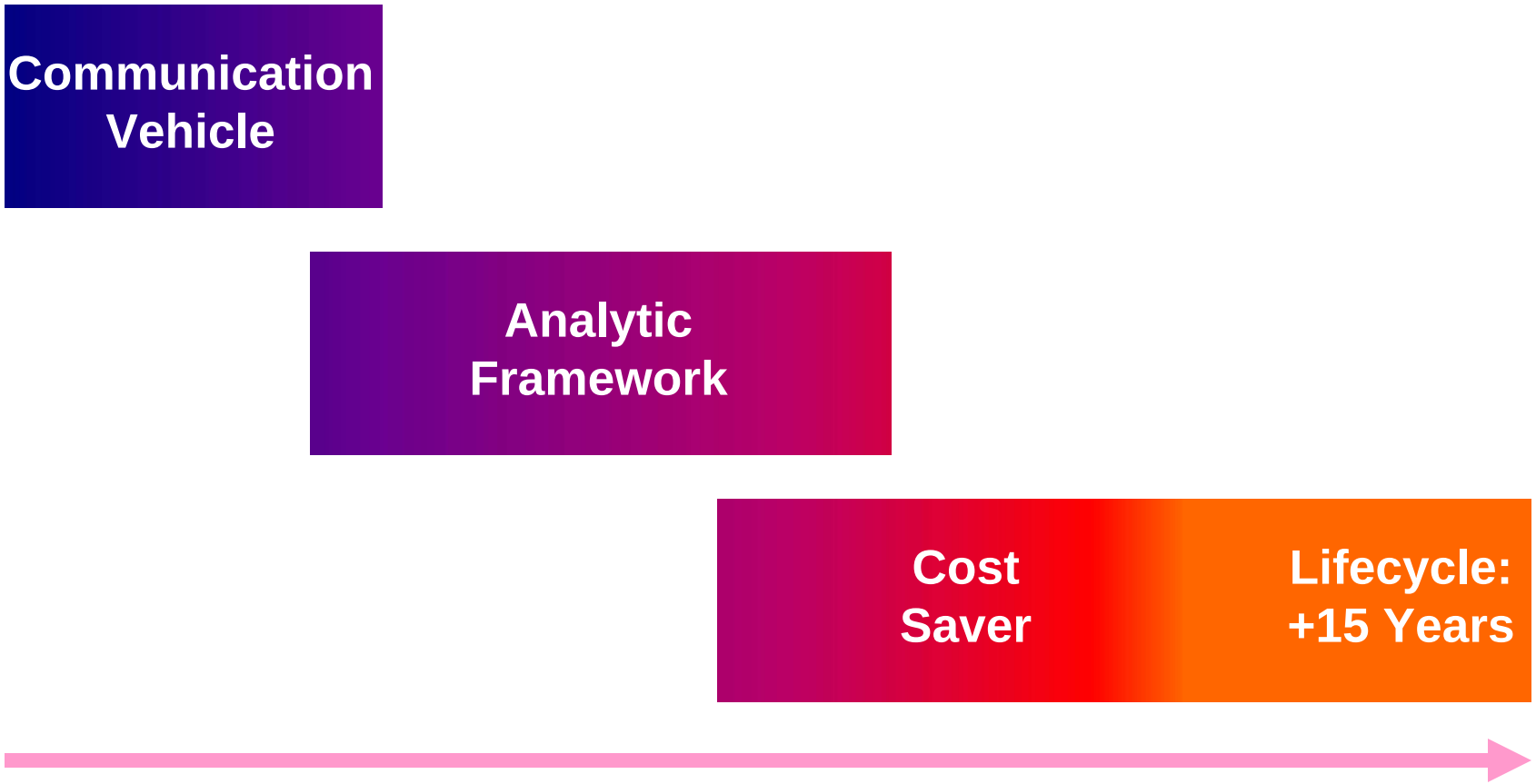
- AY 2000/2 parallel tested
- AY 2001/1 deployed

	Legacy System + human deconflicter	New System
Individual Relaxations	203/304/116	58/25/4
Capacity Overloads	12/54	9/21
Number of Schedulers	3	1
Time to produce Schedule	4 Weeks	1 Day

Cost Saver

- Most convincing and obvious reason for using an optimization model
- *Science of better (INFORMS)*
- Often exaggerated/difficult to estimate
- More reasons:
  - Institutionalize personal knowledge
  - Scientific foundation (economic models)
  - Get "*fair*" results (usually fails)

Model Roles over Time



Long Term Commitment

- Backward compatibility
- New Solvers/Platforms
- Performance comparison tools: Bench / Paver
- Model converter and “encryption“ tool: Convert
- Software Quality Assurance (SQA)
  - Software configuration management
  - Quality control and tests of the product
  - Client model testing

Quality Control and Tests of the Product

- Goal: Continuous quality improvement using automated and reproducible tests
- Test libraries (available online):
  - GAMS Model Library
  - GAMS Quality Test Models Library
  - Solved for all relevant solvers: More than 16.000 solves for each platform

SQA at GAMS

- Quality Test Models Library
- Include tests to verify proper behavior of the system
- More than 140 quality test models, each containing numerous pass/fail tests:

```
abort$card(delta) 'time routines have an error';
```

- Automatic generated test summaries with different level of information

SQA at GAMS

Summary of two quality runs

```
*** Status: Normal completion
--- quality.gms(284) 4 Mb
--- quality.gms(287) 4 Mb 1 Error
There were errors: 4 out of 267 tests failed.
See the file failures.gms to reproduce the failed runs
--- Putfile this D:\support\testlib\onetest.gms
--- quality.gms(287) 4 Mb 1 Error
*** Status: Execution error(s)

==============================================

*** Status: Normal completion
--- quality.gms(284) 4 Mb
--- quality.gms(295) 4 Mb
Congratulations!  All 267 tests passed.
See the file alltests.gms to reproduce all the runs
--- Putfile this D:\support\testlib\onetest.gms
*** Status: Normal completion
```

Client Model Testing

- Client with complex application (energy management system)
- New GAMS version available:
  - Relevant new features?
  - Performance gains?
  - No „surprises“?
    - Bugs
    - Different results (e.g. MIP models)

Oops!

”After upgrading GAMS on our machines to the latest distribution, runs take about twice or three times as much time as before (3 to 4 hours instead of 1 or 1 and half). We decided to downgrade and investigate the problem later.”

Client Model Testing

- Want guarantee that their application will work with the new version
- Only limited ressources to do major testing themselves
- Confidentiality issues: Running tests without having access to internal model structures and model data (in a human readable format)

Client Model Testing

- Requires changes to the model of the clients to allow automated pass/failure tests
- Gives clients assurance that their application will also work with new GAMS releases
- Includes:
  - Ability to solve (= no bugs)
  - Returns the same solution back
  - Similar or better performance
- Improves communication between development team and clients (specific wishes)

Conclusions

- Model can contribute to a project at various stages
- Although often small in budget, the modeling tasks can become the central core in a project
- Long term commitments in various areas are necessary, new challenges in client model testing.