Using MIP to Model Midstream Energy Assets

Levi DeLissa

GUROBI OPTIMIZATION

The World's Fastest Solver

EAST DALEY CAPITAL

Welcome to the Webinar

Using MIP to Model Midstream Energy Assets

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Speaker Introduction

GUROBI OPTIMIZATION

EAST DALEY CAPITAL

Levi DeLissa

- Data Scientist at East Daley Capital
- MS in Industrial Engineering and BS in Industrial Engineering from Kansas State University
- Spent 5 years in Colorado working with East Daley Capital, helping people use data to quantify risk in the midstream energy sector
- Passionate about solving challenging problems

Using MIP to Model Midstream Energy Assets

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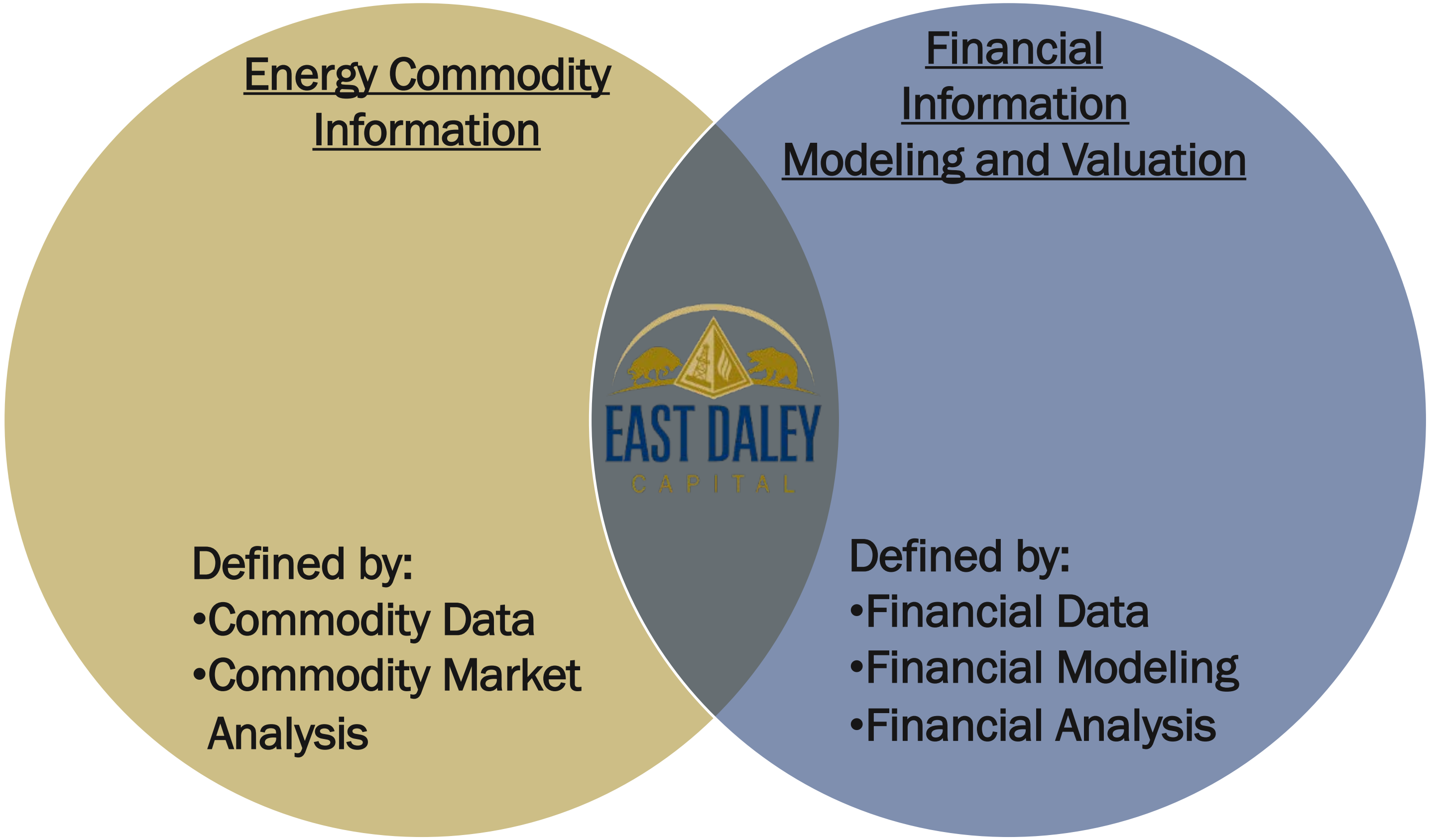
Who is East Daley?

Reshaping the way markets use data to quantify risk for North American energy infrastructure, midstream, and E&P companies



Energy Commodity Information

Defined by:
- Commodity Data
- Commodity Market Analysis

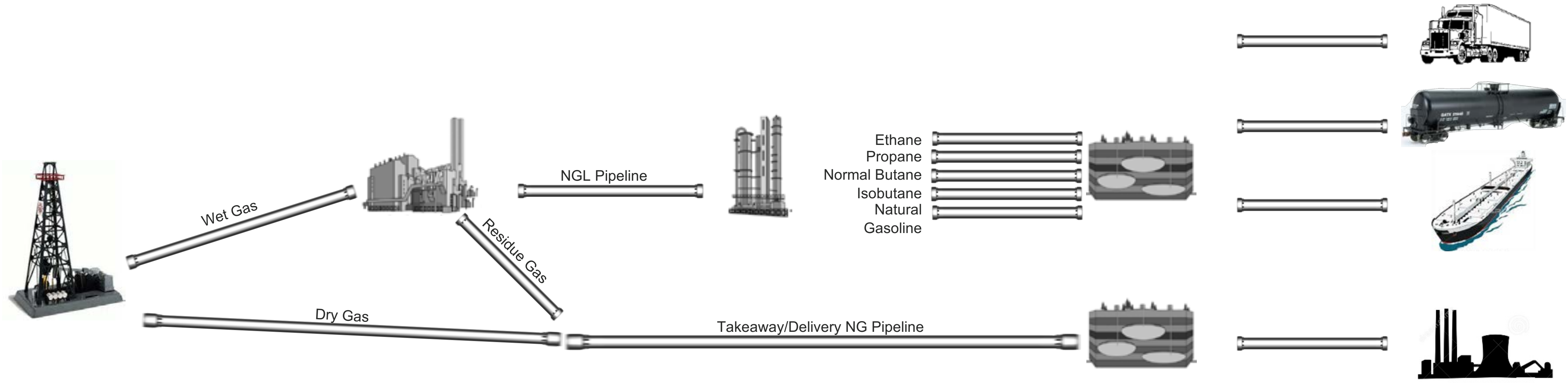
Financial Information Modeling and Valuation

Defined by:
- Financial Data
- Financial Modeling
- Financial Analysis

Midstream 101

*Simplified

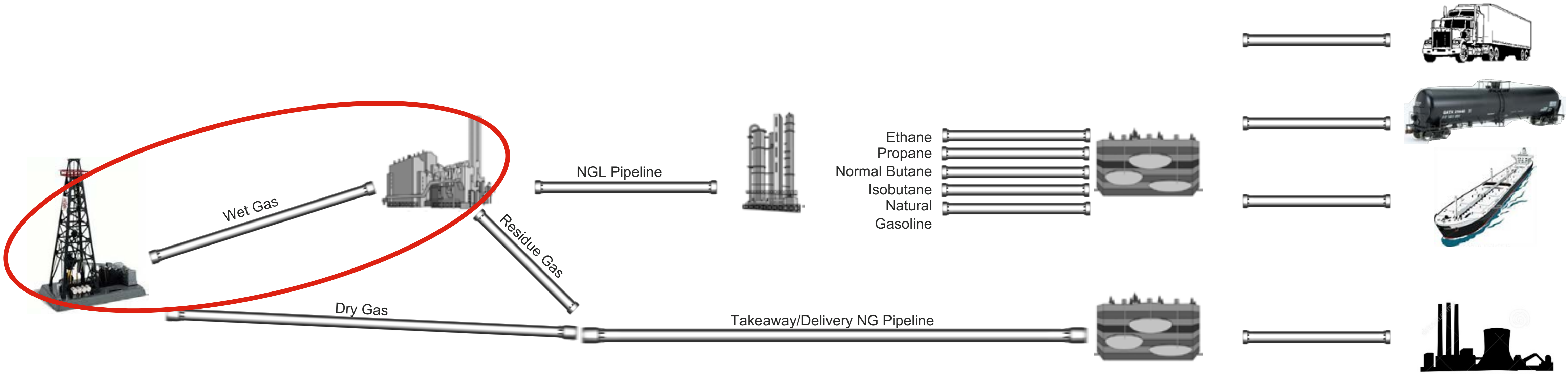
**Oil Not Included



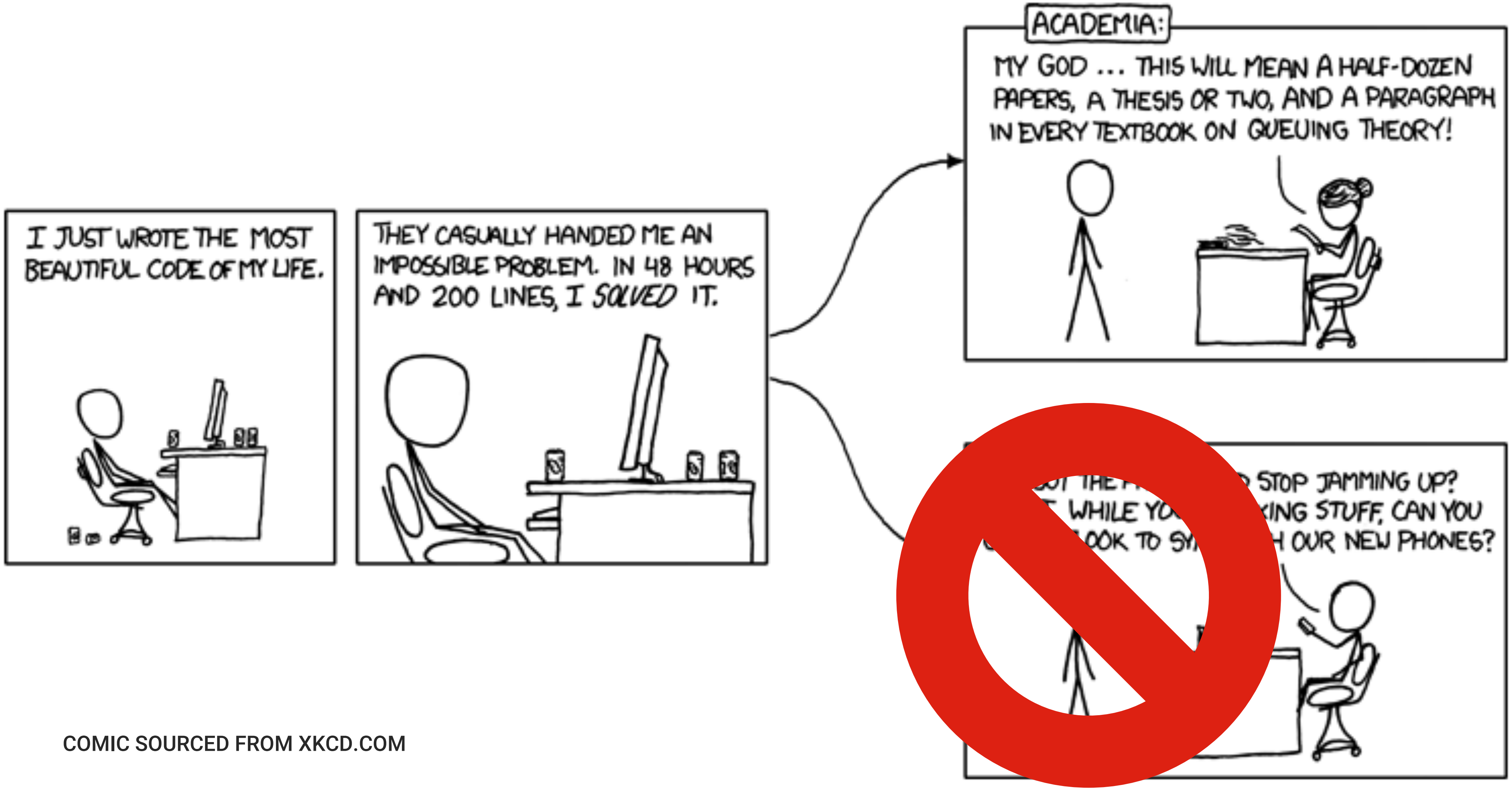
Exploration and Production	Gathering and Processing	Fractionation	Transportation and Storage	Consumption and Distribution

Some questions

- If the price of oil goes to $30 what happens?
- If there is a hurricane in South Texas what happens?
- If Chesapeake Energy is at risk of bankruptcy what happens?
- If a drilling rig drills a new well at 31.7° N, -101.9° W what happens?



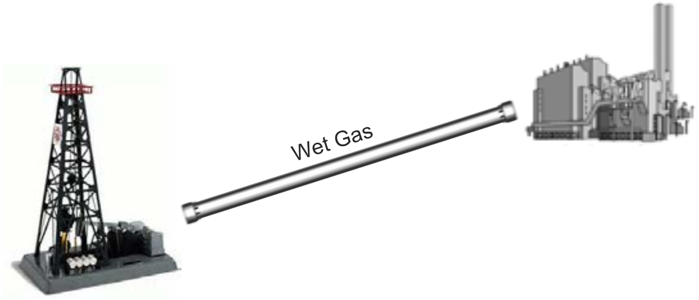
Wait… I though this was about optimization?

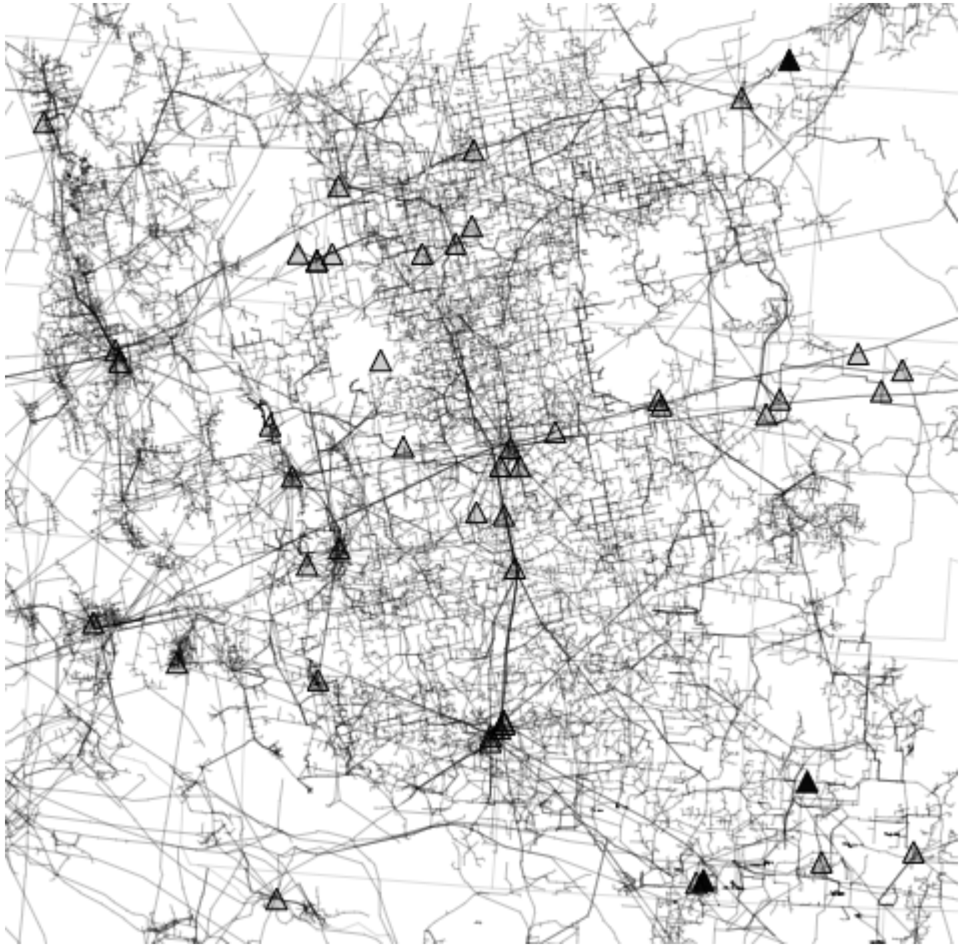

I JUST WROTE THE MOST BEAUTIFUL CODE OF MY LIFE.
THEY CASUALLY HANDED ME AN IMPOSSIBLE PROBLEM. IN 48 HOURS AND 200 LINES, I SOLVED IT.
ACADEMIA:
MY GOD … THIS WILL MEAN A HALF-DOZEN PAPERS, A THESIS OR TWO, AND A PARAGRAPH IN EVERY TEXTBOOK ON QUEUING THEORY!
STOP JAMMING UP?
WHILE YO XING STUFF, CAN YOU
OOK TO SY H OUR NEW PHONES?

COMIC SOURCED FROM XKCD.COM

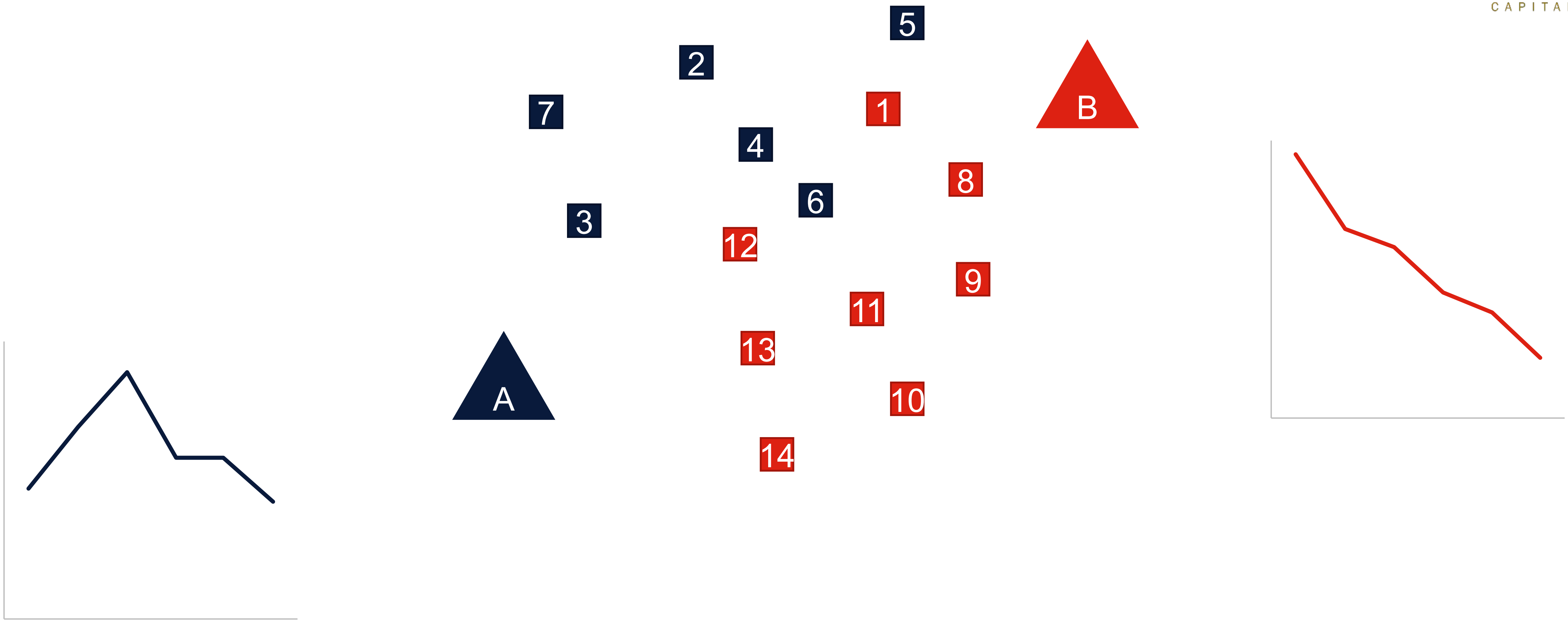
Gas Gathering & Processing

- Complex Pipeline Networks
- Hundreds of Processing Plants
  - Grouped into Systems
- Millions of Wells

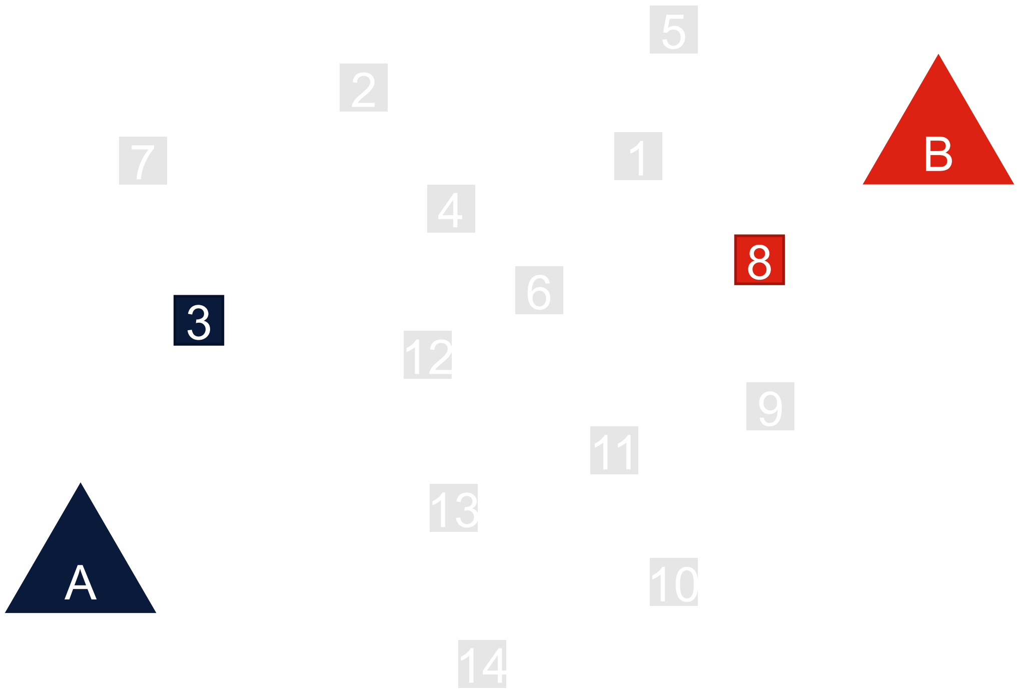


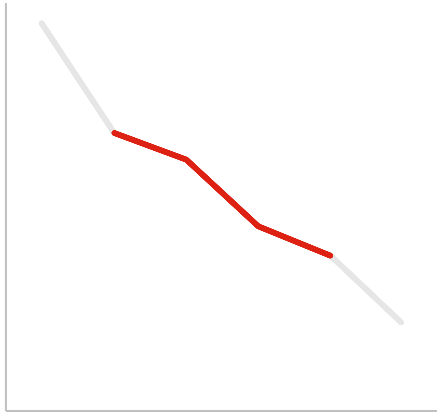


In a perfect world



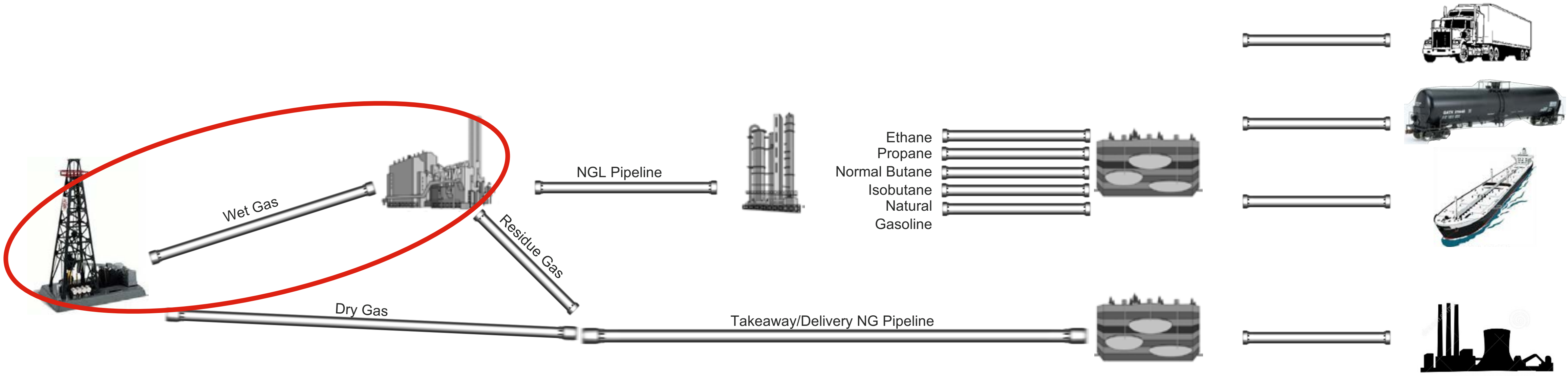
In reality





The goal

- Answer detailed questions about the midstream supply chain
- Systematically model which wells are connected to each processing system



The model

- Determine which wells provide input volumes to which G&P systems.

- Align with any known facts.
  - Volumes
  - Geography

- Given multiple choices, choose the ‘best’ one

Decision variables

- **Determine which wells provide input volumes to which G&P systems.**
  - Assume 100% volume allocation
  - Assume constant within the time period in question

- **Set of wells** W

- **Set of systems** S

- **Let** $x_{ij} \in \{0,1\}$ **be** 1 **if well** $\mathrm{i} \in W$ **is allocated to system** $j \in S$
  - $|W| * \ |S|$ binary variables
  - Logical constraint $\sum_{j \in S} x_{ij} \leq 1 \ \forall\, i \in W$

Constraints

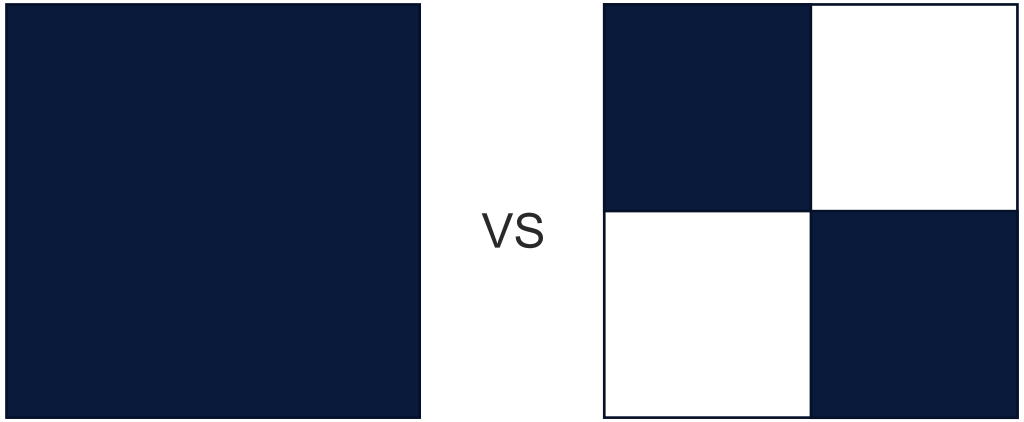
- Align with any known facts.
  - Volumes
  - Geography

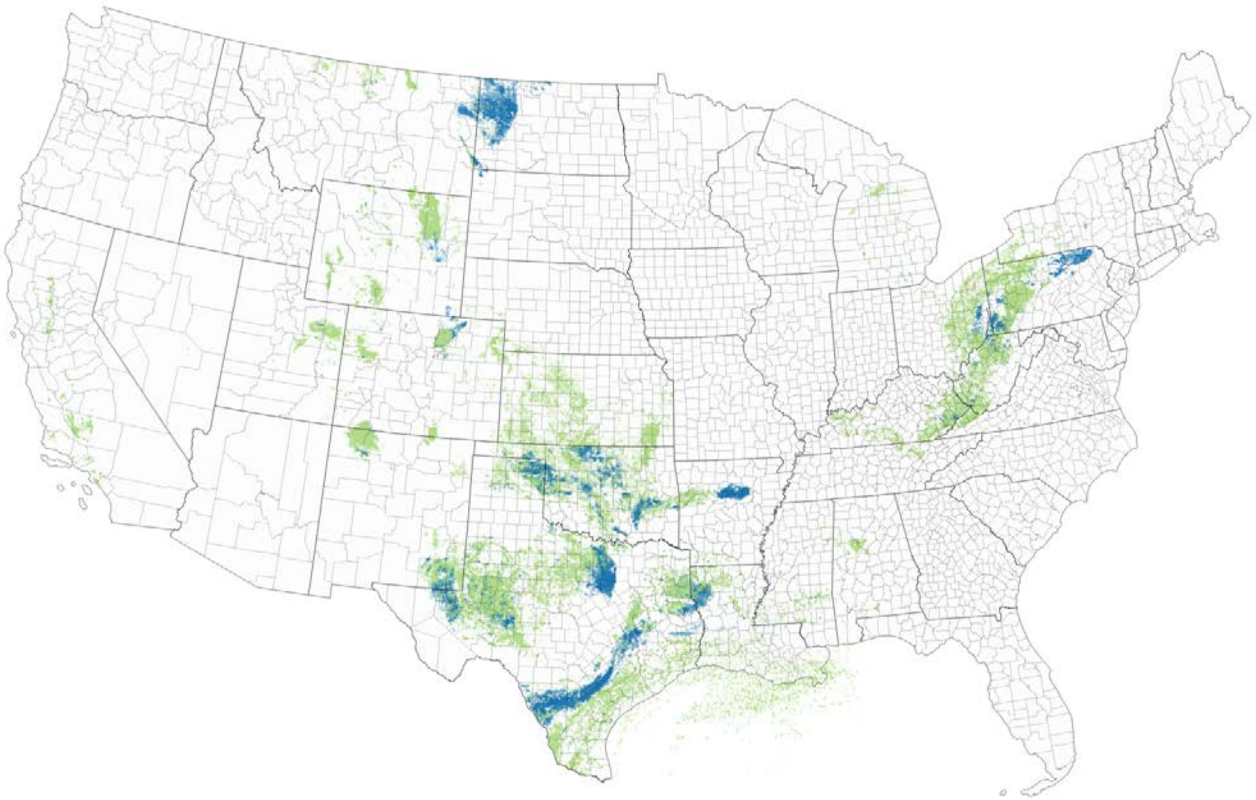
- Set of time periods T
- Set of well volumes WV
- Set of system volumes SV

- $\sum_{i \in W} x_{ij} * WV_{it} = SV_{jt} \forall\, j \in S\; t \in T$
  - $|S| * |T|$ constraints

Constraints cont.

- Align with any known facts.
  - Volumes
  - Geography





Objective

- Given multiple choices, choose the 'best' one

- Set of well to system costs C
  - Another series of models to calculate costs

- Minimize $\sum_{i \in Wells\ j \in Systems} x_{ij} * C_{ij}$

- Model is complete, but not likely to be feasible (or useful)

Revisiting infeasible constraints

- $\sum_{i \in W} x_{ij} * WV_{it} \enclose{circle}{=} SV_{jt} \forall\, j \in S\ t \in T$

- **Reformulate as a ‘soft’ constraint(s)**
  - Add variable $f \in \mathbb{R}^{+}$ which represents units of constraint violation for system j in time period t
  - $\sum_{i \in W} x_{ij} * WV_{it} \; - f_{ijt} \leq SV_{jt} \forall\, j \in S\ t \in T$
  - $\sum_{i \in W} x_{ij} * WV_{it} + f_{ijt} \geq SV_{jt} \forall\, j \in S\ t \in T$
  - Add $\sum_{i \in W\ j \in S\ t \in T} f_{ijt}$ to objective function to minimize violation

Linear constraints

- **Linear constraints can exactly model many things**
  - If then
  - Either or
  - Max and Min

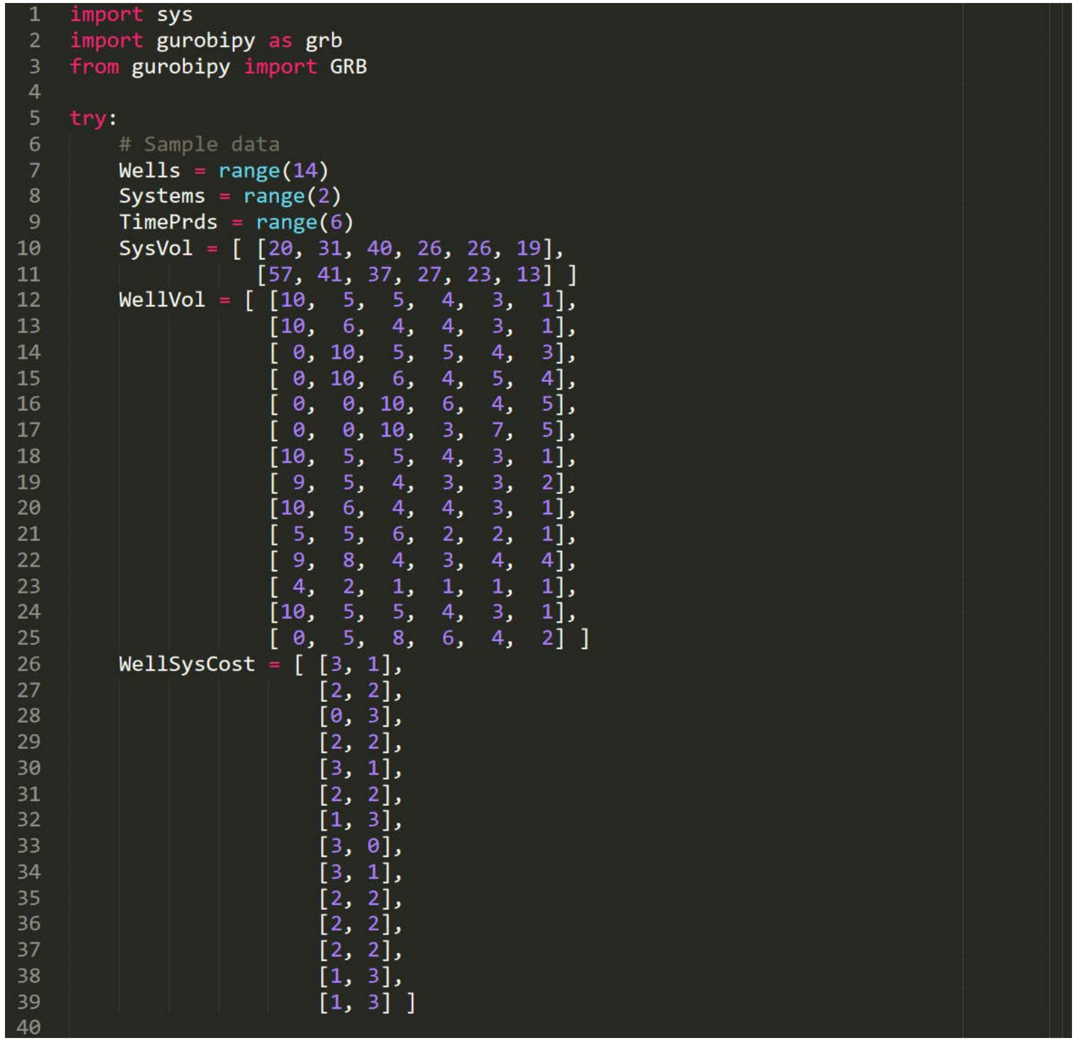
- **Linear constraints can approximate many things**
  - Piecewise functions

- **Still encounter non-linear**

Multiple objectives

- When working with ‘soft’ constraints importance can be an issue
- Two approaches
  - Weighted
  - Hierarchy
- You can do the work yourself, or you can let Gurobi take care of this under the hood

Implementation - Setup

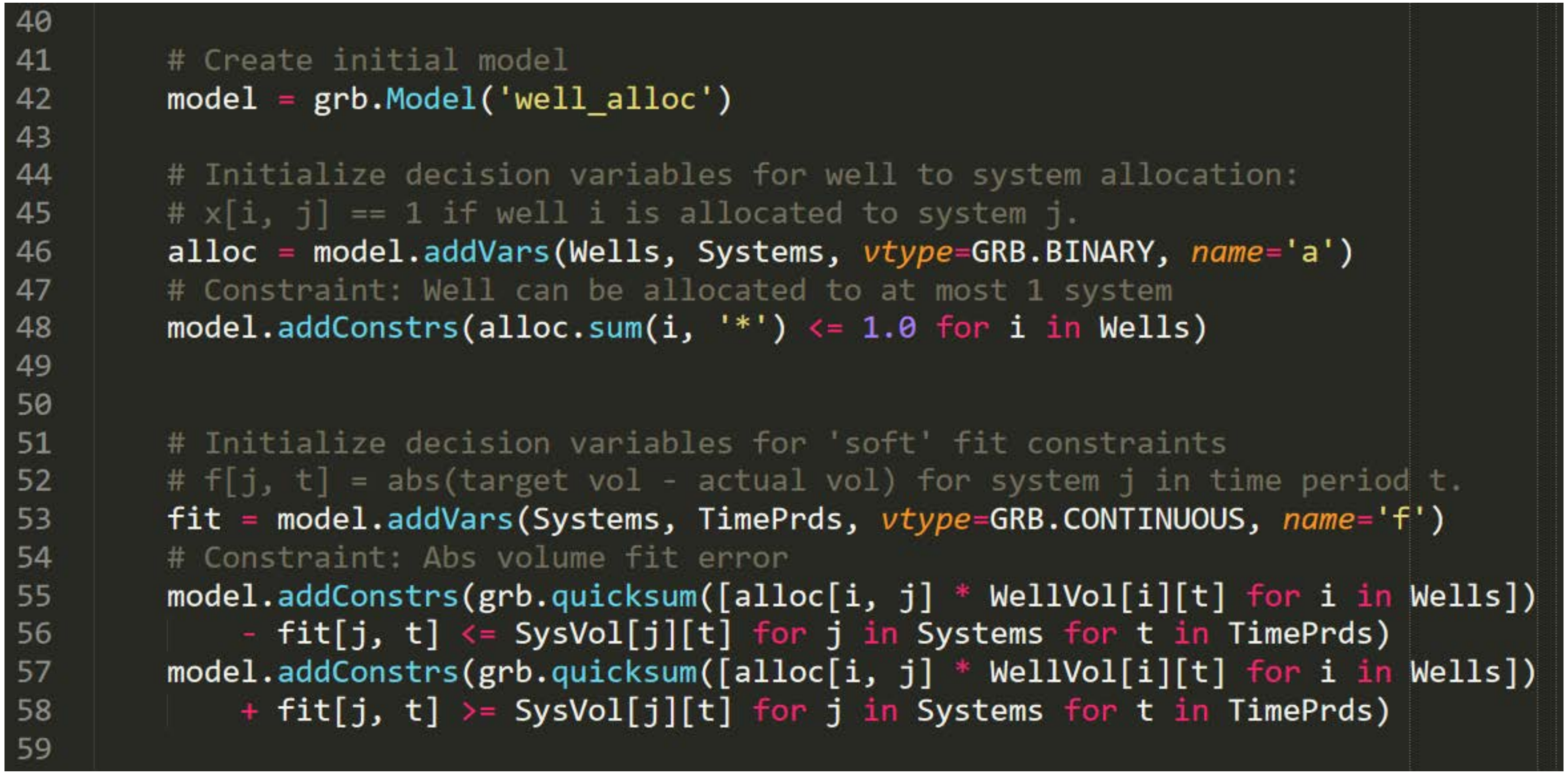


```python
import sys
import gurobipy as grb
from gurobipy import GRB

try:
    # Sample data
    Wells = range(14)
    Systems = range(2)
    TimePrds = range(6)
    SysVol = [ [20, 31, 40, 26, 26, 19],
               [57, 41, 37, 27, 23, 13] ]
    WellVol = [ [10,  5,  5,  4,  3,  1],
                [10,  6,  4,  4,  3,  1],
                [ 0, 10,  5,  5,  4,  3],
                [ 0, 10,  6,  4,  5,  4],
                [ 0,  0, 10,  6,  4,  5],
                [ 0,  0, 10,  3,  7,  5],
                [10,  5,  5,  4,  3,  1],
                [ 9,  5,  4,  3,  3,  2],
                [10,  6,  4,  4,  3,  1],
                [ 5,  5,  6,  2,  2,  1],
                [ 9,  8,  4,  3,  4,  4],
                [ 4,  2,  1,  1,  1,  1],
                [10,  5,  5,  4,  3,  1],
                [ 0,  5,  8,  6,  4,  2] ]
    WellSysCost = [ [3, 1],
                    [2, 2],
                    [0, 3],
                    [2, 2],
                    [3, 1],
                    [2, 2],
                    [1, 3],
                    [3, 0],
                    [3, 1],
                    [2, 2],
                    [2, 2],
                    [2, 2],
                    [1, 3],
                    [1, 3] ]

```

Implementation – Variables & Constraints



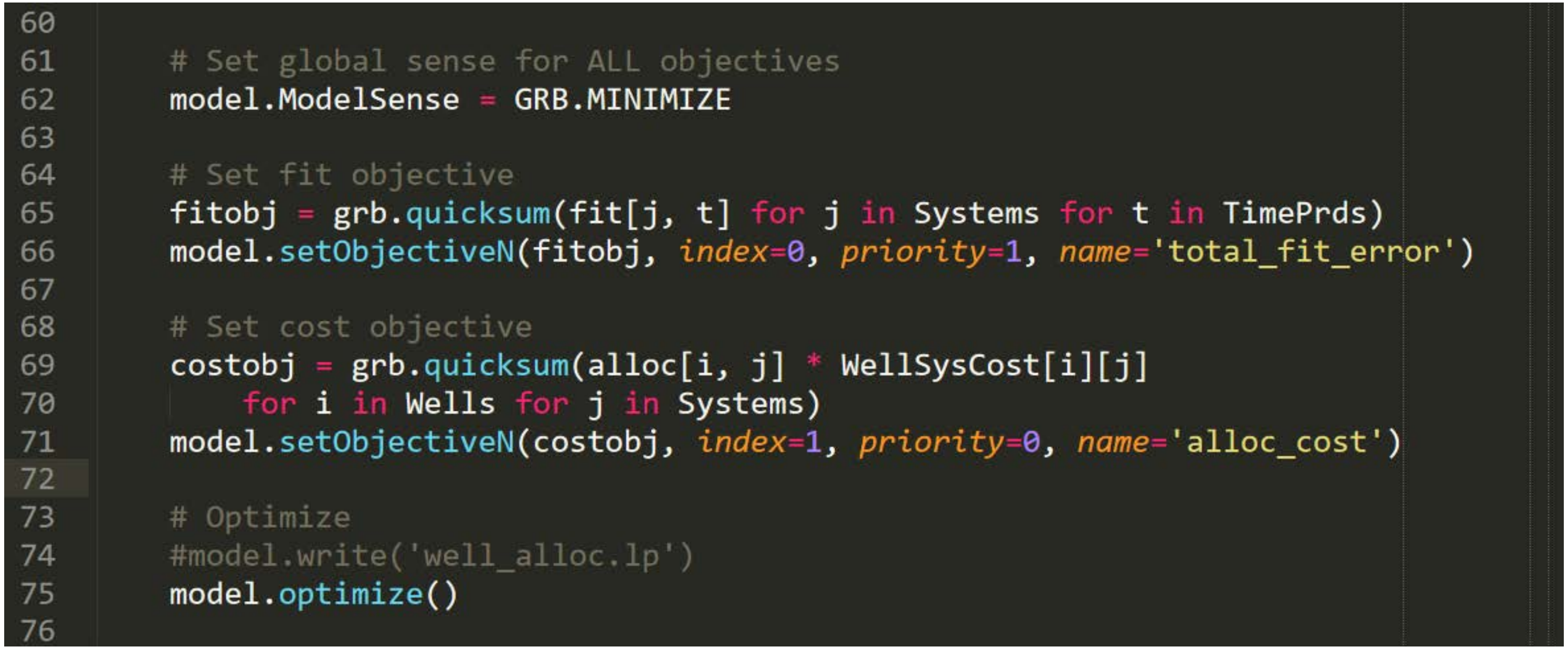
```
    # Create initial model
    model = grb.Model('well_alloc')

    # Initialize decision variables for well to system allocation:
    # x[i, j] == 1 if well i is allocated to system j.
    alloc = model.addVars(Wells, Systems, vtype=GRB.BINARY, name='a')
    # Constraint: Well can be allocated to at most 1 system
    model.addConstrs(alloc.sum(i, '*') <= 1.0 for i in Wells)


    # Initialize decision variables for 'soft' fit constraints
    # f[j, t] = abs(target vol - actual vol) for system j in time period t.
    fit = model.addVars(Systems, TimePrds, vtype=GRB.CONTINUOUS, name='f')
    # Constraint: Abs volume fit error
    model.addConstrs(grb.quicksum([alloc[i, j] * WellVol[i][t] for i in Wells])
        - fit[j, t] <= SysVol[j][t] for j in Systems for t in TimePrds)
    model.addConstrs(grb.quicksum([alloc[i, j] * WellVol[i][t] for i in Wells])
        + fit[j, t] >= SysVol[j][t] for j in Systems for t in TimePrds)

```

Implementation - Objective



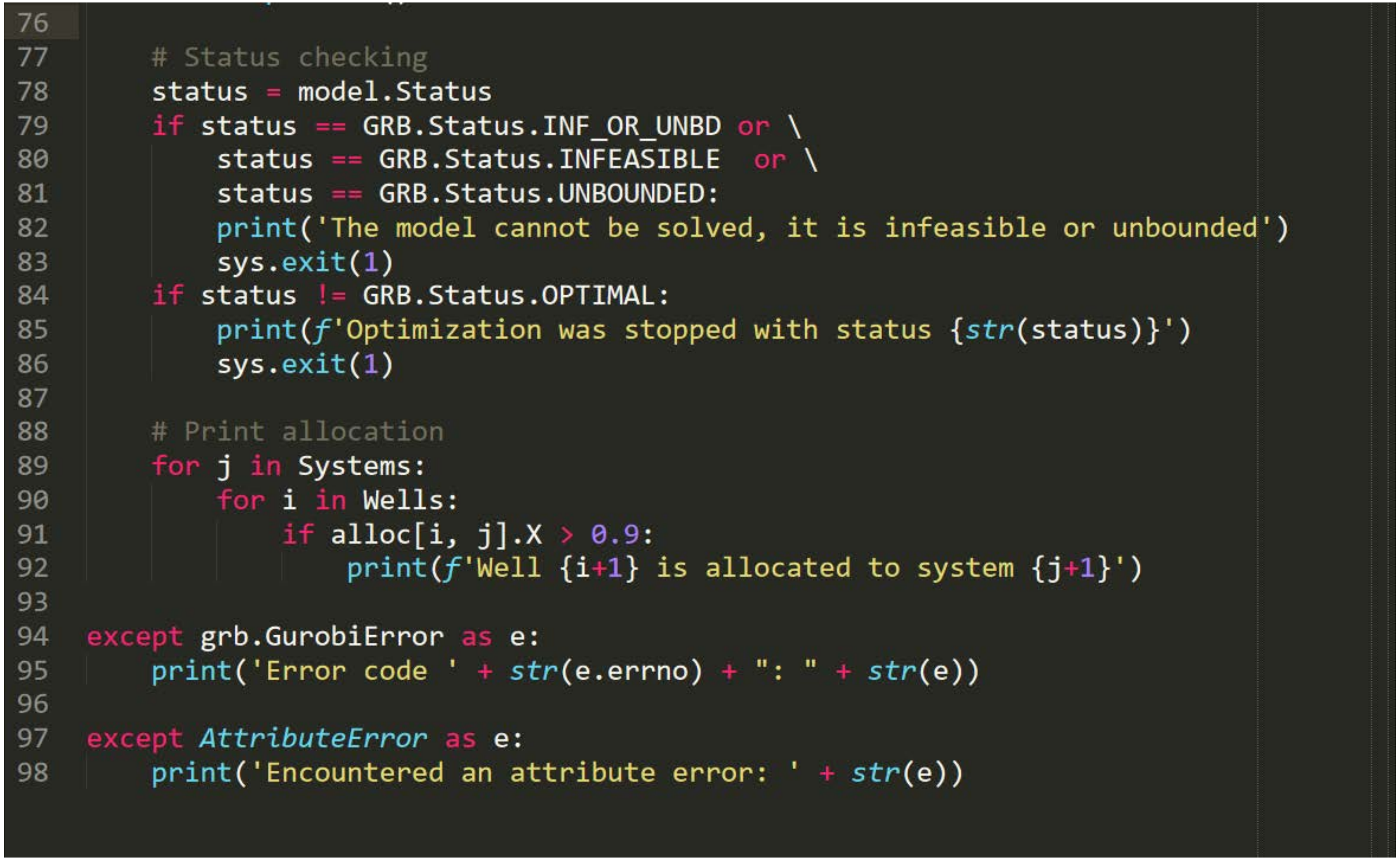
```
    # Set global sense for ALL objectives
    model.ModelSense = GRB.MINIMIZE

    # Set fit objective
    fitobj = grb.quicksum(fit[j, t] for j in Systems for t in TimePrds)
    model.setObjectiveN(fitobj, index=0, priority=1, name='total_fit_error')

    # Set cost objective
    costobj = grb.quicksum(alloc[i, j] * WellSysCost[i][j]
        for i in Wells for j in Systems)
    model.setObjectiveN(costobj, index=1, priority=0, name='alloc_cost')

    # Optimize
    #model.write('well_alloc.lp')
    model.optimize()
```

Implementation – Process Solution



```python

    # Status checking
    status = model.Status
    if status == GRB.Status.INF_OR_UNBD or \
        status == GRB.Status.INFEASIBLE  or \
        status == GRB.Status.UNBOUNDED:
        print('The model cannot be solved, it is infeasible or unbounded')
        sys.exit(1)
    if status != GRB.Status.OPTIMAL:
        print(f'Optimization was stopped with status {str(status)}')
        sys.exit(1)

    # Print allocation
    for j in Systems:
        for i in Wells:
            if alloc[i, j].X > 0.9:
                print(f'Well {i+1} is allocated to system {j+1}')

except grb.GurobiError as e:
    print('Error code ' + str(e.errno) + ": " + str(e))

except AttributeError as e:
    print('Encountered an attribute error: ' + str(e))
```

Variable hints

- Data is always changing
- Depending on region of country model runs can take from seconds to 24+ hours.
- Typically doesn't make catastrophic changes to the solution
- Variable hints can help algorithm make good decisions based on outside knowledge
- Drastically reduce time required to update models with new data

Closing thoughts

- **MIP is an excellent framework for stating a problem**
  - Not just big decision making
  - Modeling process helpful to understand problem
- **Advances in hardware/software have greatly expanded the scope of what is possible**
- **Using MIP for G&P allocation has some beneficial properties**
  - Can’t prove model wrong without making it better
  - Simple framework for adding new categories of ‘facts’
  - Balanced
  - Gap/Bounds provide some sense of opportunity
  - Patent pending
- **Gurobi features can significantly speed up development time (and accuracy)**

Thank You – Questions?

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Your Next Steps

- If you haven’t already done so, please register for an account at http://www.gurobi.com
- For questions about Gurobi pricing contact sales@gurobi.com or sales@gurobi.de
- A recording of this webinar, including the slides, will be available in roughly one week