

The IBM Research Uncertainty Toolkit for Decision Optimization

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Product Manager, Joint Research Program Manager

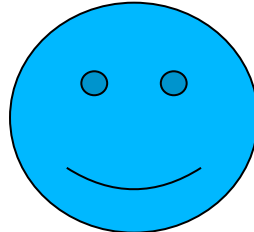
IBM Decision Optimization & IBM Research



Project team



Alain Chabrier
Advisor, ILOG



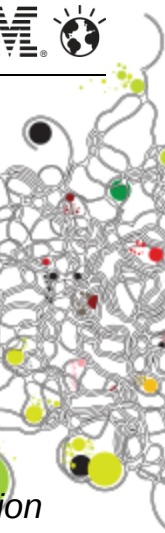
Various Decision
Optimization
colleagues



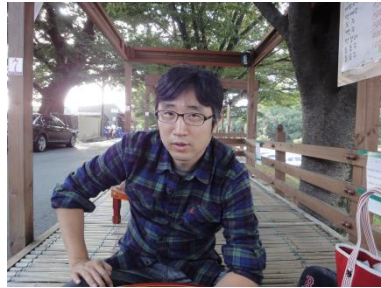
Ban Kawas (WRL)
Robust optimization



Ali Koc (WRL)
Stochastic optimization



Marco Laumanns (ZRL)
Robust/stochastic



Chungmok Lee (DRL)
Robust optimization



Radu Marinescu (DRL)
Stochastic CP



Martin Mevissen (DRL)
Robust optimization



Susara van den Heever (DRL / ILOG)
Project manager



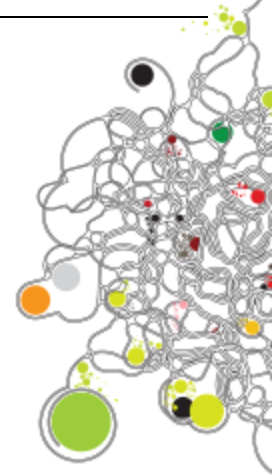
Rudi Verago (DRL)
Software engineering



Nicole Taheri (DRL)
Robust optimization

Outline

- Overview of IBM Decision Optimization Center
- Industry context
- Project goals & benefits
- Uncertainty Toolkit design and architecture
- Case studies
 - Pump scheduling for energy cost minimization with uncertain energy prices
 - Pressure management for leakage reduction with uncertain water demand
 - Energy Unit Commitment with uncertain demand



IBM Decision Optimization Portfolio

Engines and Tools

CPLEX Optimization Studio

High-performance mathematical programming solvers and development tools

Solution Platform

Decision Optimization Center

Build and deploy analytical decision support applications based on optimization technology

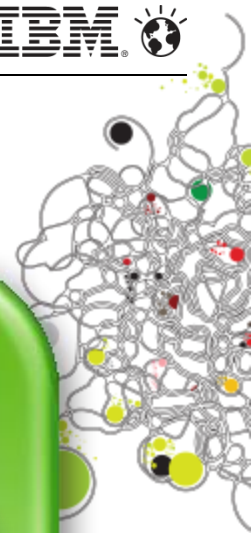
Industry Solutions

Optimization Assets

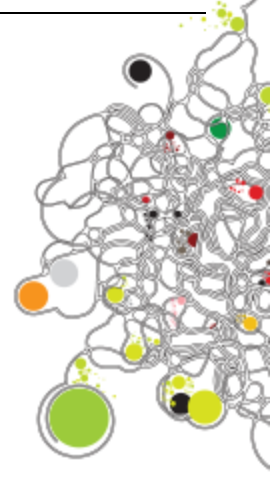
Pre-built yet customizable industry applications

Integrated Analytics

- Decision support solutions for **Supply Chain Management**
- **SPSS** predictive analytics
- **Cognos** descriptive analytics
- **Maximo** asset management

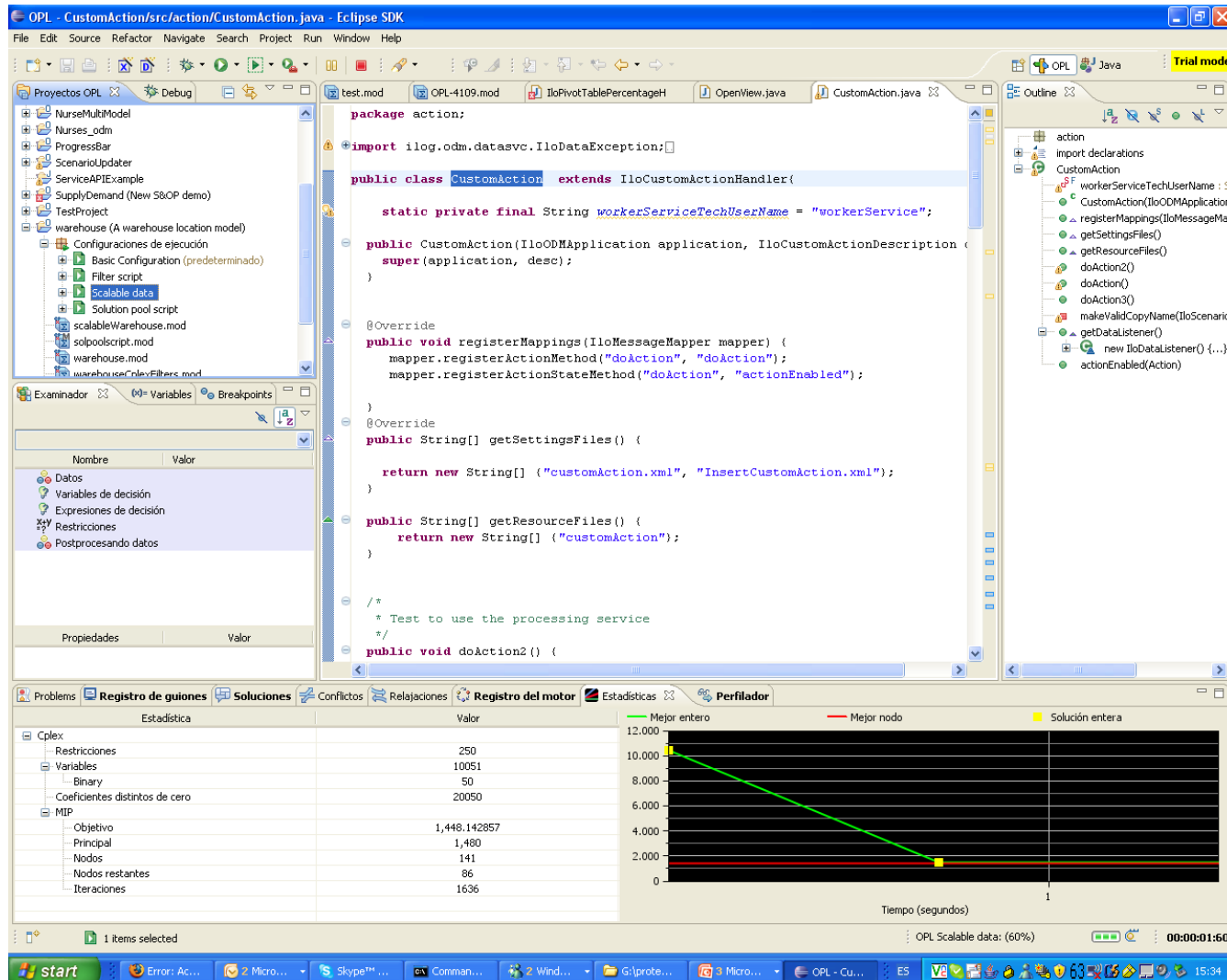


Decision Optimization Center is about Decision Support



- We support a business expert making the decision
- A Business User need
 - Manual planning in addition to Optimization
 - Recommendations
 - Explanations
 - Alternatives
 - Relaxations
 - Tradeoffs
 - Re-scheduling functionalities
 - Insight on solution sensitivity and robustness
 - “What-if” and scenario comparison

Decision Optimization Center hIDE OPL Models Development



The screenshot displays the Eclipse IDE interface for OPL development. The main editor shows the `CustomAction.java` file, which implements the `IloCustomActionHandler` interface. The code includes imports, class declarations, and methods for registering mappings, getting settings files, and getting resource files.

The `CustomAction.java` code is as follows:

```
package action;

import ilog.odm.dataexc.IloDataException;

public class CustomAction extends IloCustomActionHandler{

    static private final String workerServiceTechUserName = "workerService";

    public CustomAction(IloODMApplication application, IloCustomActionDescription desc) {
        super(application, desc);
    }

    @Override
    public void registerMappings(IloMessageMapper mapper) {
        mapper.registerActionMethod("doAction", "doAction");
        mapper.registerActionStateMethod("doAction", "actionEnabled");
    }

    @Override
    public String[] getSettingsFiles() {

        return new String[] { "customAction.xml", "InsertCustomAction.xml" };
    }

    public String[] getResourceFiles() {
        return new String[] { "customAction" };
    }

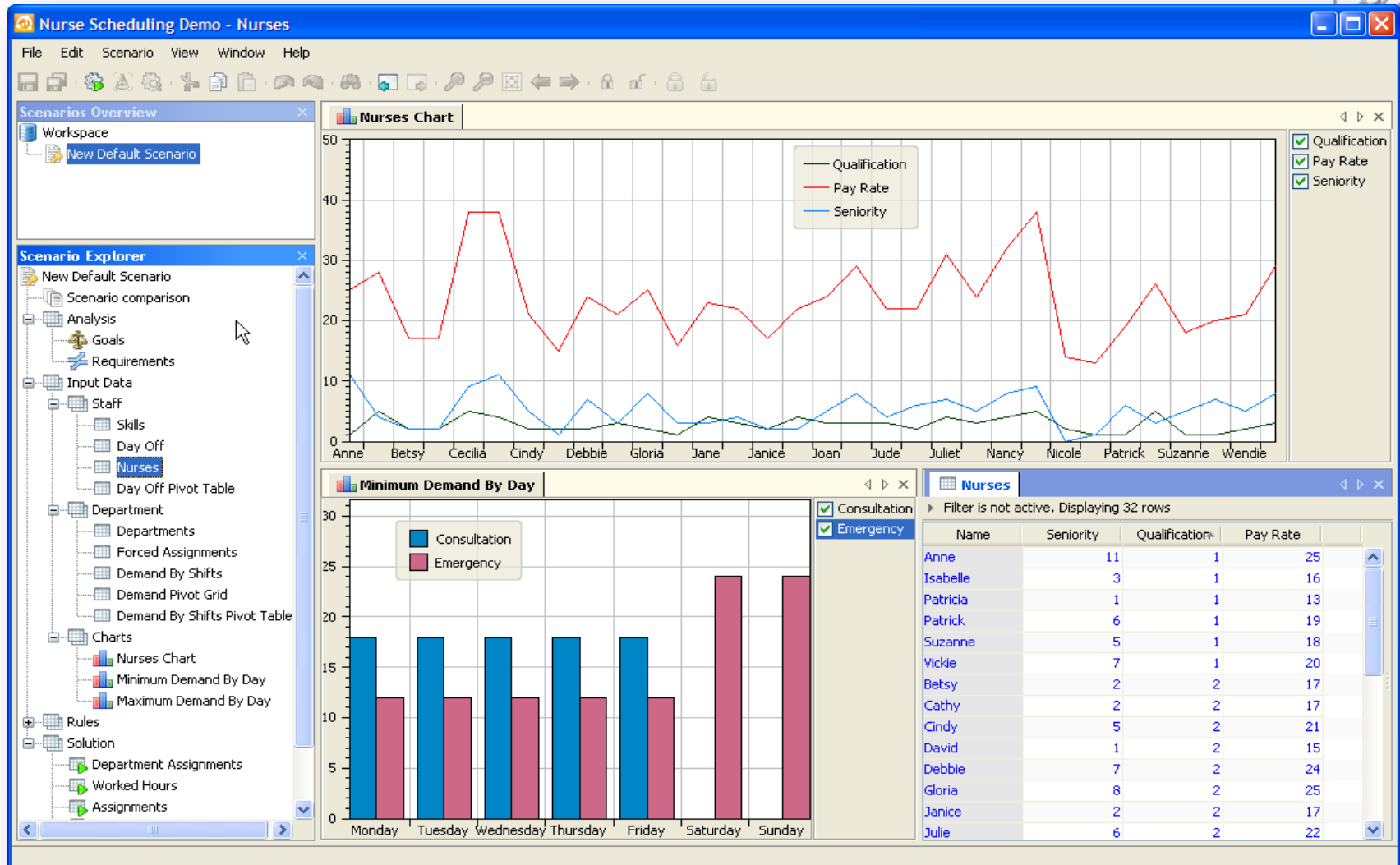
    /*
     * Test to use the processing service
     */
    public void doAction2() {
    }
}
```

The bottom panel shows the **Registro de guiones** (Script Log) window, which displays the execution statistics for the OPL model. The table below summarizes the data shown in the window:

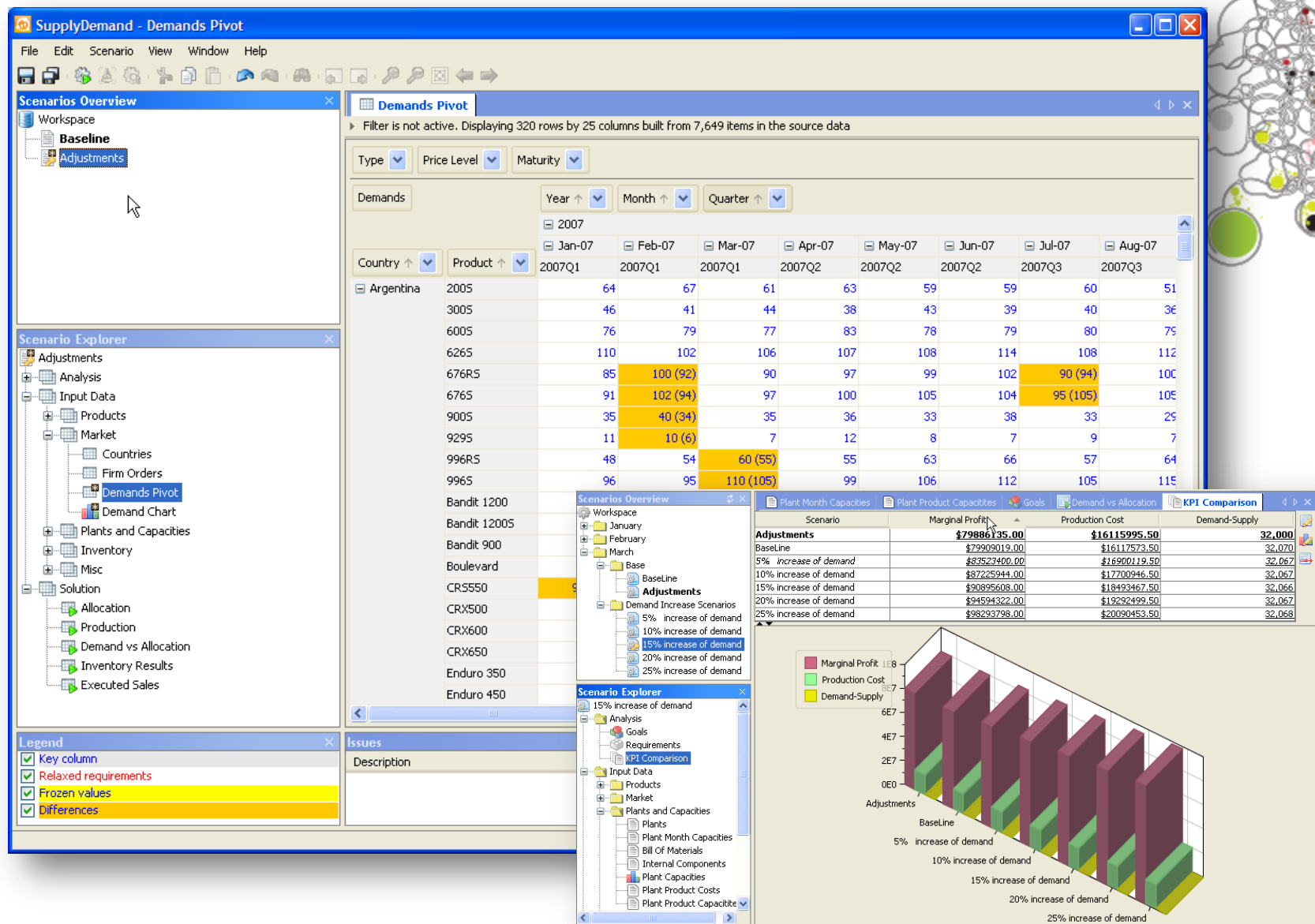
Estadística	Valor
Cplex	
Restricciones	250
Variables	10051
Binary	50
Coefficientes distintos de cero	20050
MIP	
Objetivo	1,448.142857
Principal	1,480
Nodos	141
Nodos restantes	86
Iteraciones	1636

The right side of the bottom panel shows a graph titled **OPL Scalable data: (60%)**. The graph plots the number of nodes (Nodos) against time (Tiempo (segundos)). The y-axis ranges from 0 to 12,000, and the x-axis ranges from 0 to 1. The graph shows a green line representing the 'Mejor entero' (Best integer) solution, which starts at approximately 10,000 nodes and decreases to about 2,000 nodes. A red line represents the 'Mejor nodo' (Best node) solution, which remains relatively flat around 1,500 nodes. A yellow line represents the 'Solución entera' (Integer solution), which is shown as a single point at the end of the x-axis.

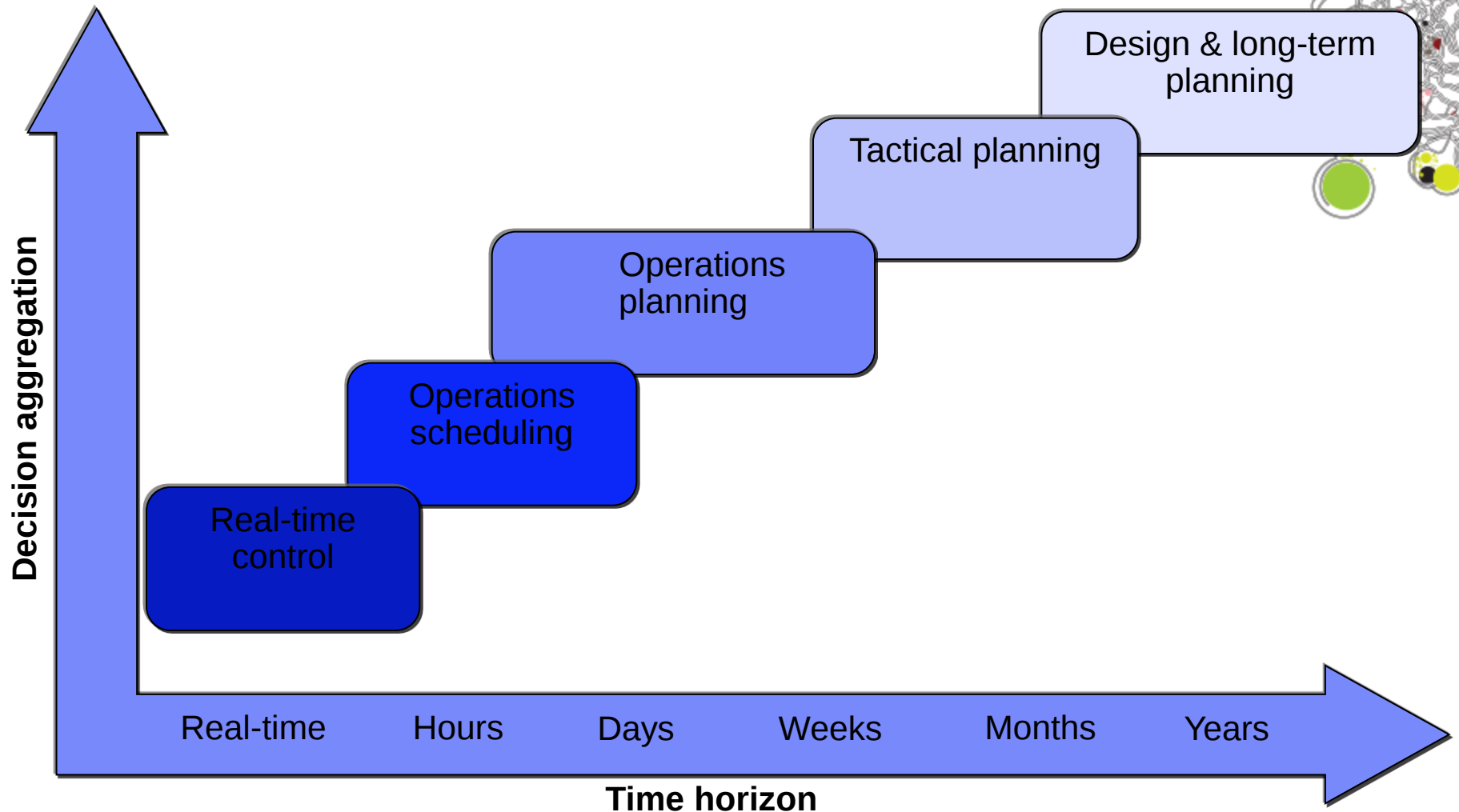
Displays using Simple Tables and Charts – out of the box



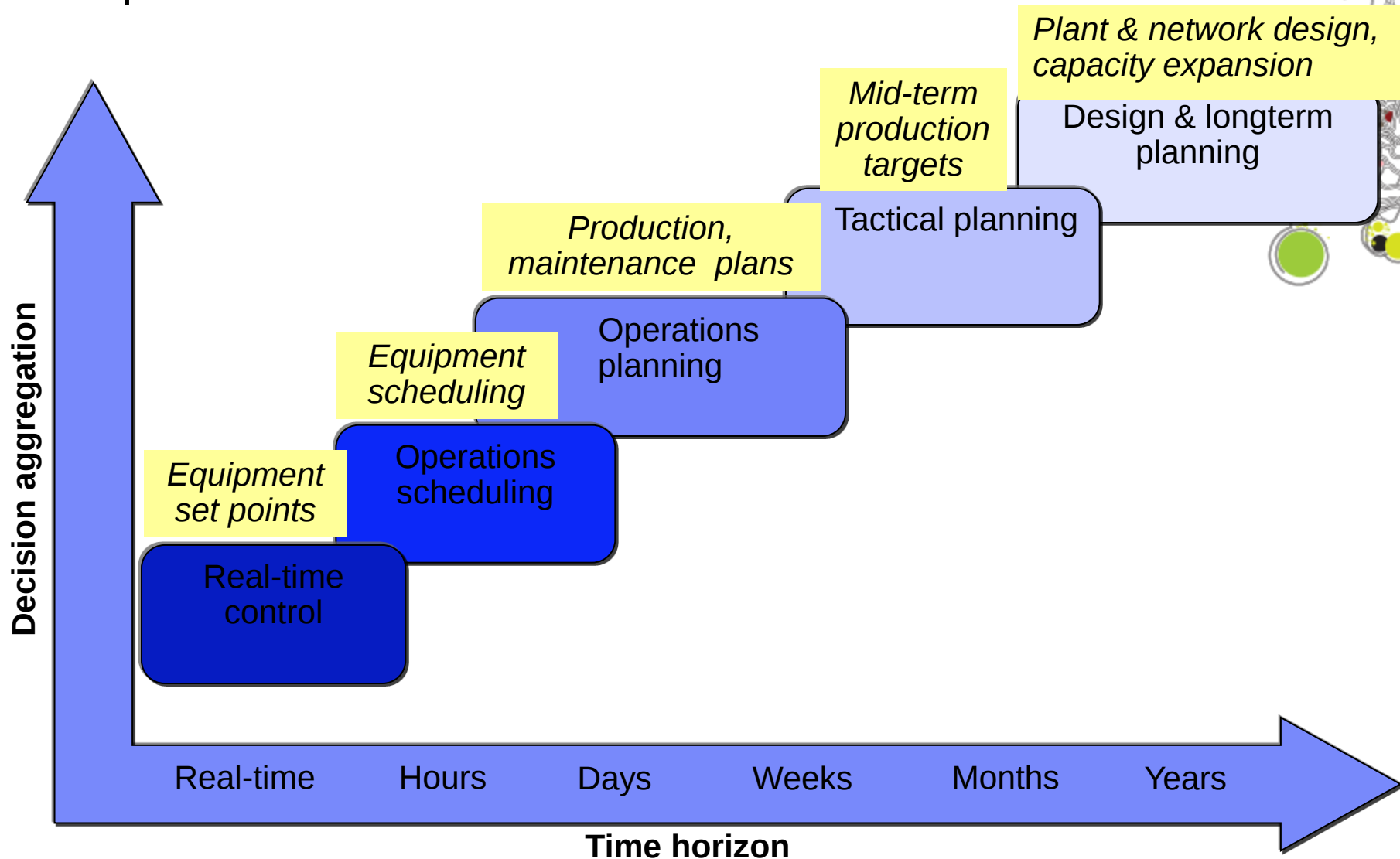
Pivot Tables and Scenario Comparison – out of the box



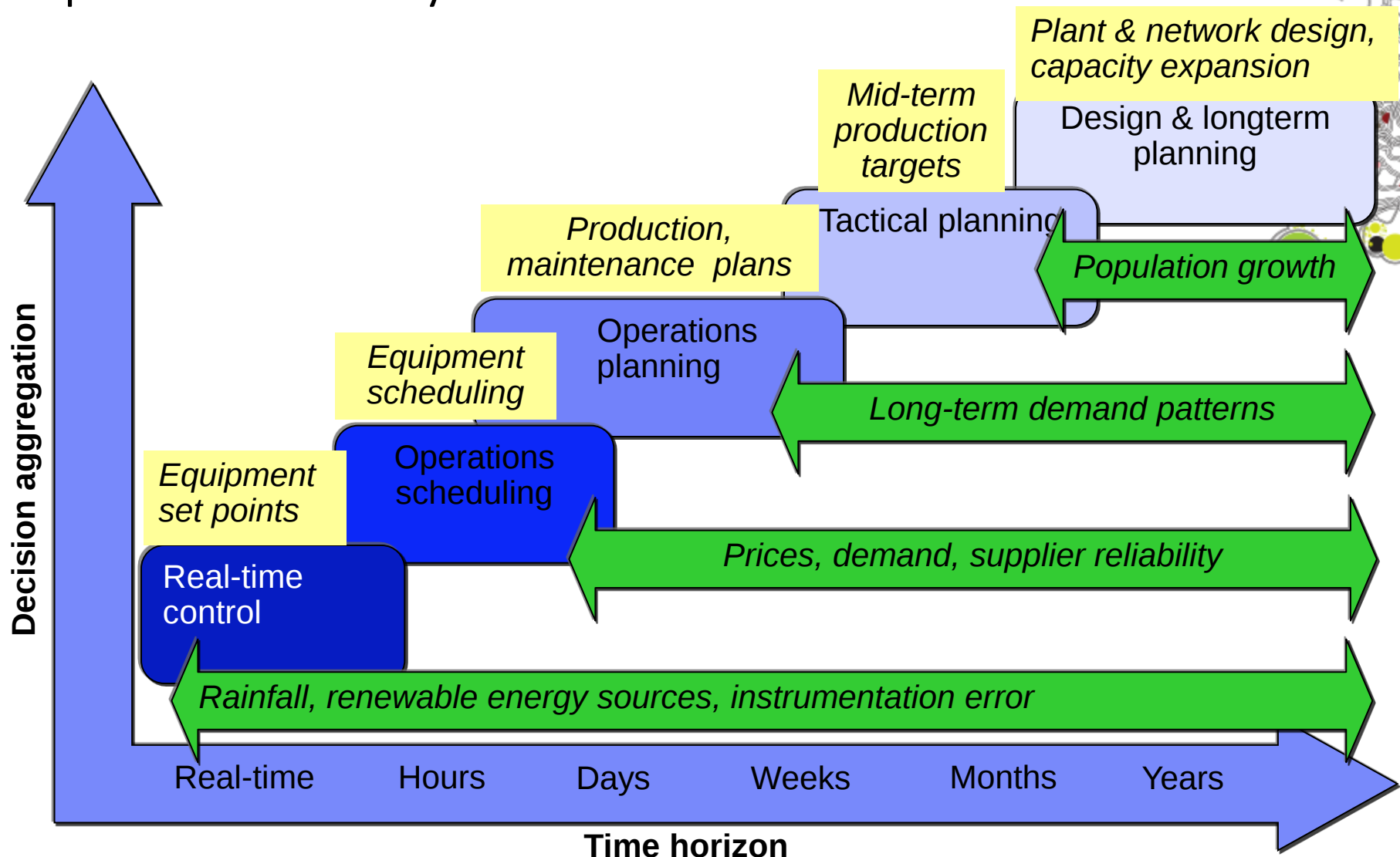
Planning levels



Examples of decisions



Impact of uncertainty



Effect of data uncertainty on decision resilience

“Resilient”

how decisions should be

re·sil·ient¹

adjective \ri-ˈzil-yənt\
a : capable of withstanding shock without permanent deformation or rupture
b : tending to recover from or adjust easily to misfortune or change

“Veracity”

the data quality decision makers and decision software often assume

ve·rac·i·ty¹

noun \və-ˈra-sə-tē\
: truth or accuracy

“Uncertain”

the actual data quality

un·cer·tain¹

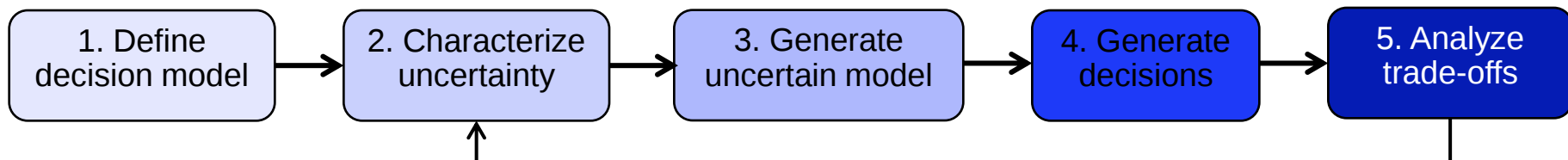
adjective \,ən-ˈsər-tən\
: not exactly known or decided : not definite or fixed
: not sure : having some doubt about something

Assuming data veracity in the face of **uncertainty** leads to decision **instability**, as well as **distrust** in decision optimization technology.

Uncertainty Toolkit goals

- 2013 Joint Program between IBM Research and Decision Optimization
- Goals
 - Increase customer solution resilience, reliability, and stability
 - Improve trust & understanding of optimization technology
- Our approach
 - Leverage Decision Optimization & mathematical optimization to hedge against uncertainty (e.g. uncertain demand, task durations, prices, resource availability)
 - A user-friendly toolkit as plug-in to Decision Optimization Center

■ *5 steps to resilient decisions in the face of uncertainty*



Stable decisions, stable profits

■ Test examples

- Supply chain planning for a motorcycle vendor

2% increase in profits vs. deterministic optimization

- Inventory optimization for IBM Microelectronics Division

Greater than 7x increase in feasibility vs. deterministic optimization

■ Case studies

- Energy cost minimization for Cork County Council

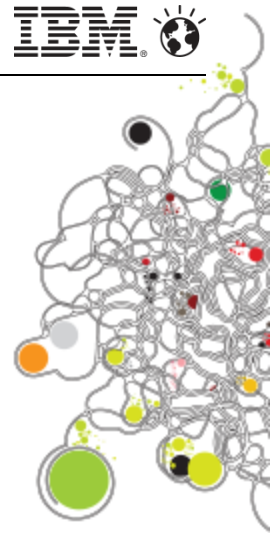
Estimated 30% value-add in cost reduction vs. deterministic optimization

- Leakage reduction for Dublin City Council

Estimated 10 times increased stability vs. deterministic optimization

• Other benefits

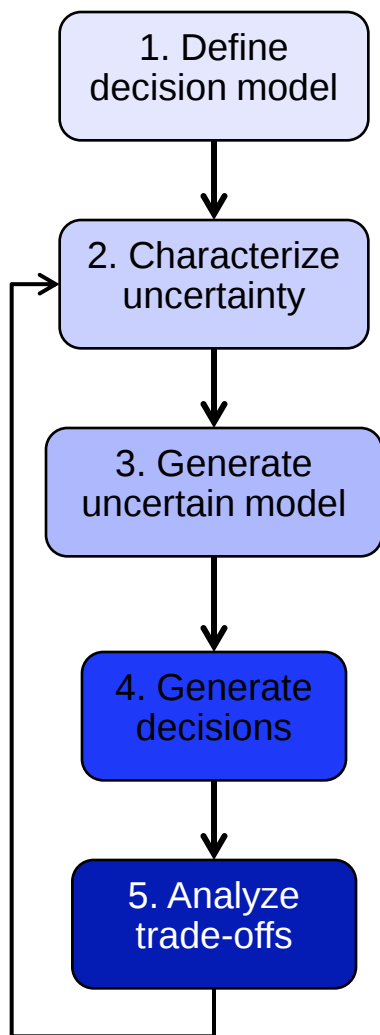
- Automated toolkit reduces dependence on PhD-level experts & statistical data
- Visualize trade-off between multiple KPIs across multiple scenarios and plans



Example use cases for the Uncertainty Toolkit

Industry	Typical company	Problem type
Government	Government agencies	Project portfolio management
Tourism	Hotel operators, Airlines	Revenue management
Transport	Railroads	Railroad locomotive planning
Transport	Supermarket chain, cement	Delivery / pick-up truck routing
Utilities	Electricity company	Production planning
Utilities	Water company	Tactical reservoir planning
Utilities	Water company	Water distribution network configuration
Utilities	Electricity company	Unit commitment
Utilities	Water network operators	Pump scheduling
Utilities	Water network operators	Pressure management
Utilities	Electricity company	Energy trading
Oil and gas	Oil company	Vessel scheduling
Manufacturing	Manufacturer	Operational project scheduling
Manufacturing	Car manufacturer	Manufacturing line load balancing
Manufacturing	Aircraft manufacturer	Plant assembly
Manufacturing	Car manufacturer	Sales and operations planning
Supply chain	Manufacturer	Contractor to transport leg assignment
Supply chain	Manufacturer	Product to store allocation
Supply chain	Manufacturer, oil&gas	Inventory optimization
Supply chain	Manufacturer, oil&gas	Supply chain network configuration
Supply chain	Manufacturer	Procurement planning
Supply chain	Manufacturer	Emergency operations planning
Commercial	Banks, insurance, TV	Marketing campaign optimization
Finance	Banks	Collateral allocation

5 steps to resilience with the Uncertainty Toolkit



- Create optimization model with IBM CPLEX Studio
- Some modeling skill required, or existing assets
- Embed in IBM Decision Optimization Center

“Steve” the IT expert, &
“Keith” the OR consultant

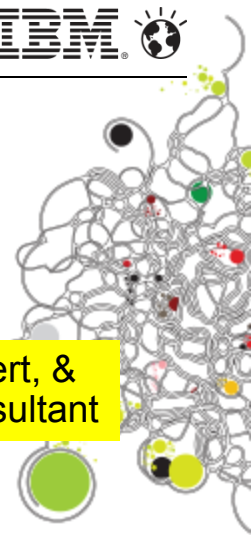
- OR consultant’s “wizard”: 7 screens
- Defines uncertainty, scenario generation, risk measures

- Built-in automated reformulation, based on steps 1 and 2
- No modeling knowledge required
- “Robustification” (make the original model robust to change)

- Business user’s “wizard”
- Automated solution generation
- Automated scenario comparison

“Anne” the business user

- Built-in visual analytics
- Analyze KPI trade-offs across multiple plans & scenarios



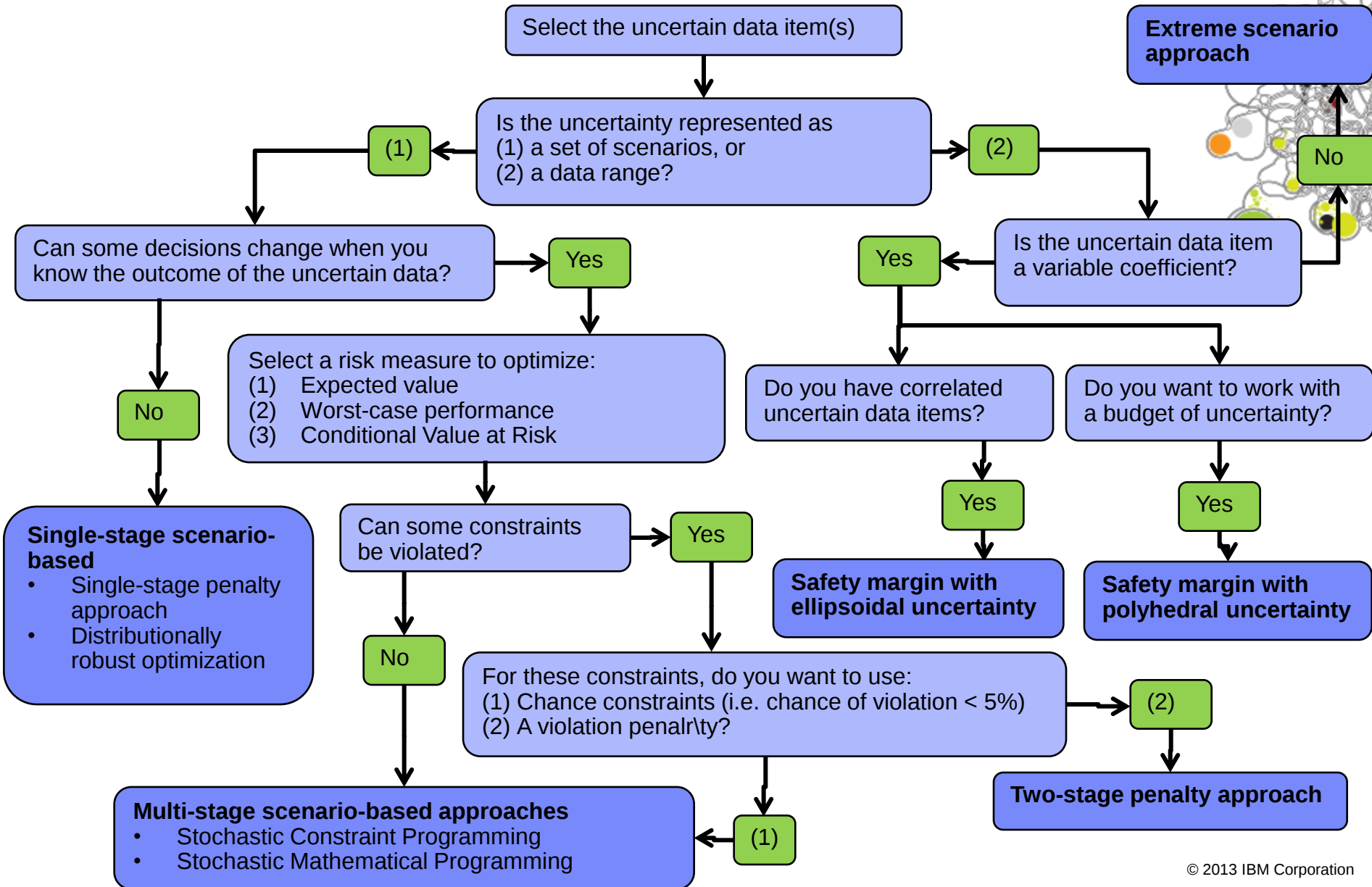
Uncertainty Toolkit: automated reformulations

Robust / Stochastic approach	Applicable model types	Resulting model types	Uncertainty characterization	Restrictions
Single-stage penalty approach (<i>Mulvey et al., 1995</i>)	LP	LP (or QP)	Scenarios (finite)	No uncertain data in objective function
	MILP	MILP (or MIQP)		
Two-stage penalty approach (<i>Mulvey et al., 1995</i>)	LP	LP (or QP)	Scenarios (finite)	No uncertain data in objective function
	MILP	MILP (or MIQP)		
Multistage Stochastic (e.g. <i>King & Wallace, 2012</i>)	LP	LP	Scenarios (finite)	None
	MILP	MILP		
Safety margin approach with ellipsoidal uncertainty sets (<i>Ben-Tal & Nemirovski, 1999</i>)	LP	QCP	Range	No uncertain data in standalone parameters or equality constraints
	MILP	MIQCP		
Safety margin approach with polyhedral uncertainty sets (<i>Bertsimas & Sim, 2004</i>)	LP	LP	Range	No uncertain data in standalone parameters or equality constraints
	MILP	MILP		
Extreme Scenario approach (<i>Lee, 2014</i>)	LP	LP	Range	No uncertain data in variable coefficients
	MILP	MILP		
Distributionally robust reformulation (<i>Mevissen et al., 2013</i>)	LP	LP	Scenarios	Uncertainty in standalone parameters handled as penalty term in objective
	MILP	MILP		

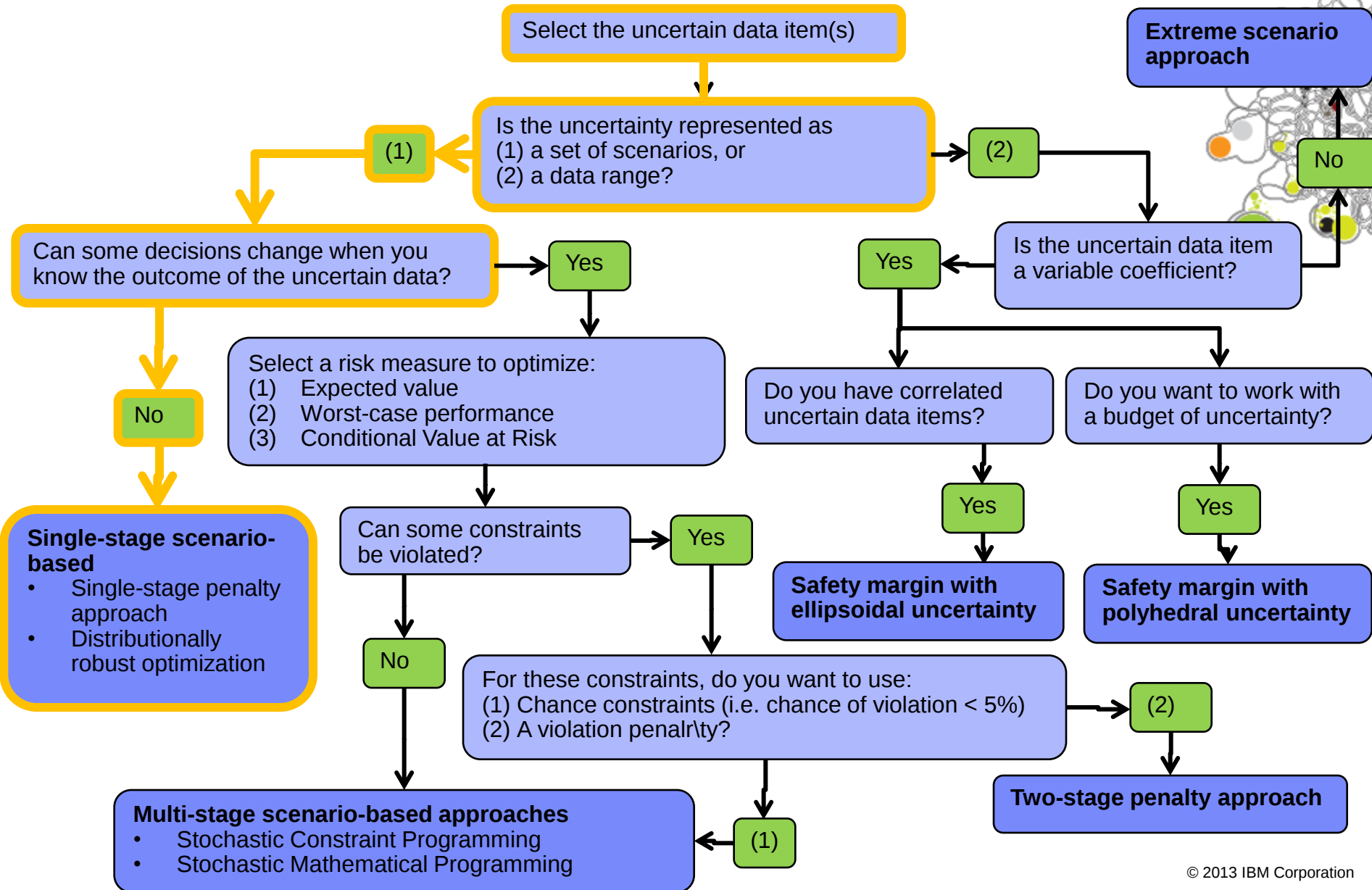
Uncertainty Toolkit: automated reformulations

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	MILP	MILP (or MIQP)		
Multistage Stochastic (e.g. <i>King</i>)	LP	LP	Scenarios (finite)	None
Safety margin approach with ellipsoidal uncertainty sets (<i>Ben-Tal</i>)				Standalone
<i>Q: How do I know which of these methods to use?</i> A: The Uncertainty Toolkit will decide automatically based on your input into the Consultant's Wizard				
Safety margin approach with polyhedral uncertainty sets (<i>Bertsimas & Sim, 2004</i>)	LP	LP	Range	No uncertain data in standalone parameters or equality constraints
	MILP	MILP		
Extreme Scenario approach (<i>Lee, 2014</i>)	LP	LP	Range	No uncertain data in variable coefficients
	MILP	MILP		
Distributionally robust reformulation (<i>Mevissen et al., 2013</i>)	LP	LP	Scenarios	Uncertainty in standalone parameters handled as penalty term in objective
	MILP	MILP		

Uncertainty Toolkit Decision Tree (automated)



Uncertainty Toolkit Decision Tree (automated)



Example: Automated model reformulation for stochastic CP

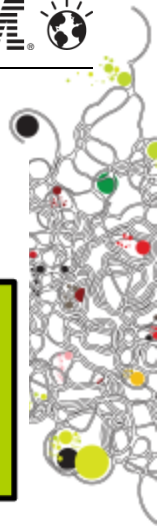
```
18
19 dvar interval task[i in 1..n] size TaskDuration[i];
20 dvar sequence seq in task types all(i in 1..n) i;
21 dexpr int station[i in 1..n] = startOf(task[i]) div c;
22
23 minimize 1+max(i in 1..n) station[i];
24 subject to {
25   noOverlap(seq, Setups);
26   forall (p in Precedences)
27     endBeforeStart(task[p.pred], task[p.succ]);
28   forall (i in 1..n)
29     station[i] == (endOf(task[i]) - 1) div c;
30 };
31 |
```

Input: Deterministic model

Automated model reformulation

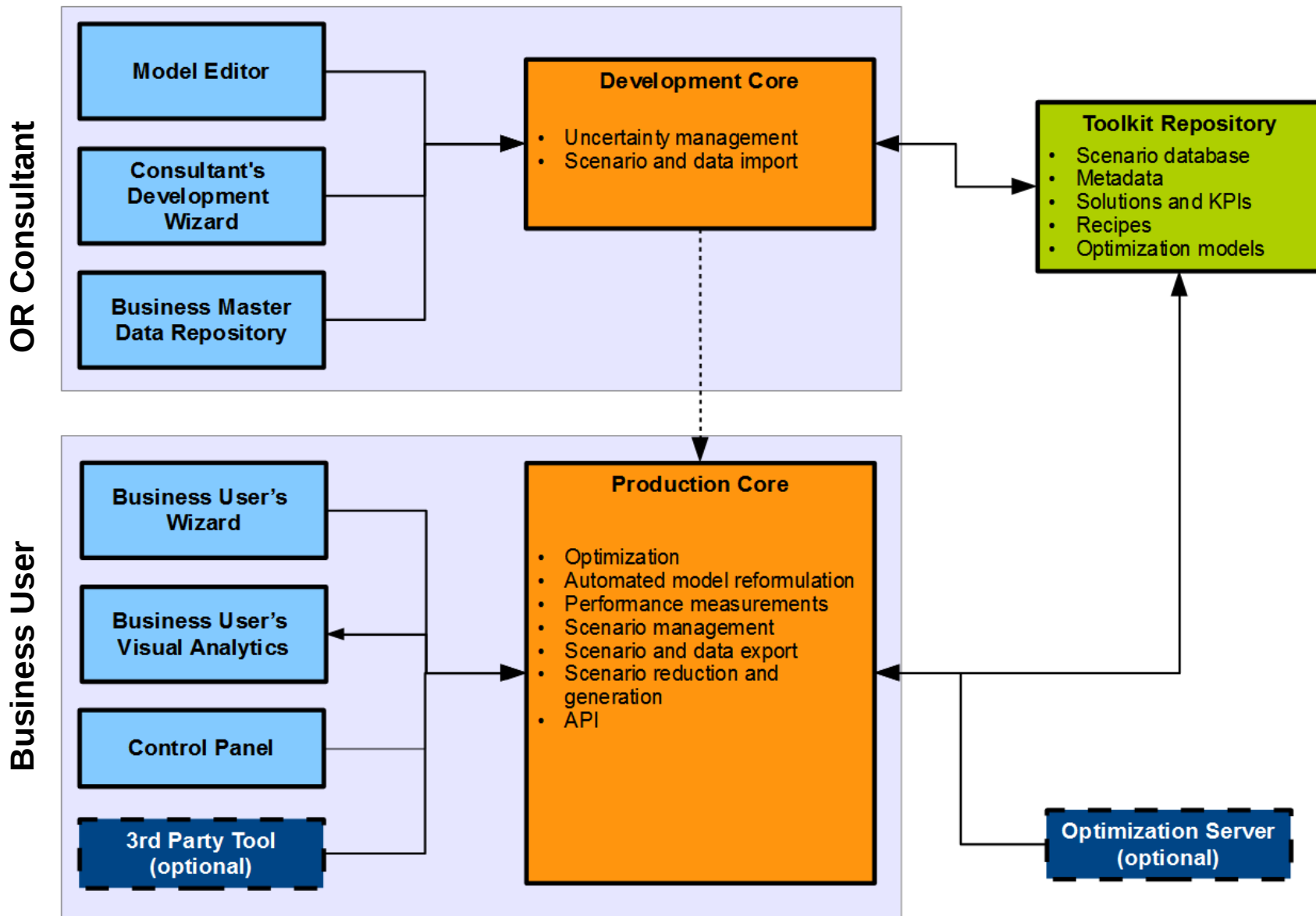
Output: Stochastic model

```
39
40 dvar interval task[i in 1..n][s in Scenarios] size TaskDuration[i][s];
41 dvar sequence seq[s in Scenarios] in all(i in 1..n) task[i][s] types all(i in 1..n) i;
42
43 dexpr int station[i in 1..n][s in Scenarios] = startOf(task[i][s]) div c;
44
45 minimize sum(s in Scenarios) Probability[s]*(1 + max(i in 1..n) station[i][s]);
46 subject to {
47
48   forall (s in Scenarios) {
49     noOverlap(seq[s], Setups);
50     forall (p in Precedences)
51       endBeforeStart(task[p.pred][s], task[p.succ][s]);
52     forall (i in 1..n)
53       station[i][s] == (endOf(task[i][s]) - 1) div c;
54   }
55
56   forall (s in 1..(S-1), i in 1..n) {
57     typeOfNext(seq[s], task[i][s], -1) == typeOfNext(seq[s+1], task[i][s+1], -1);
58   }
59 };
60
61 |
```



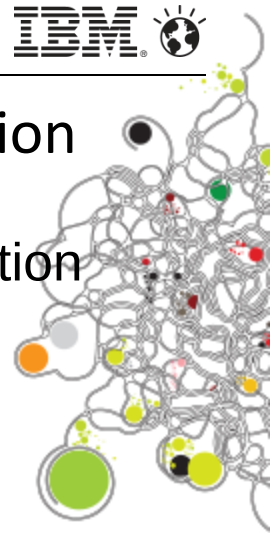
Decision Optimization

Uncertainty Toolkit architecture



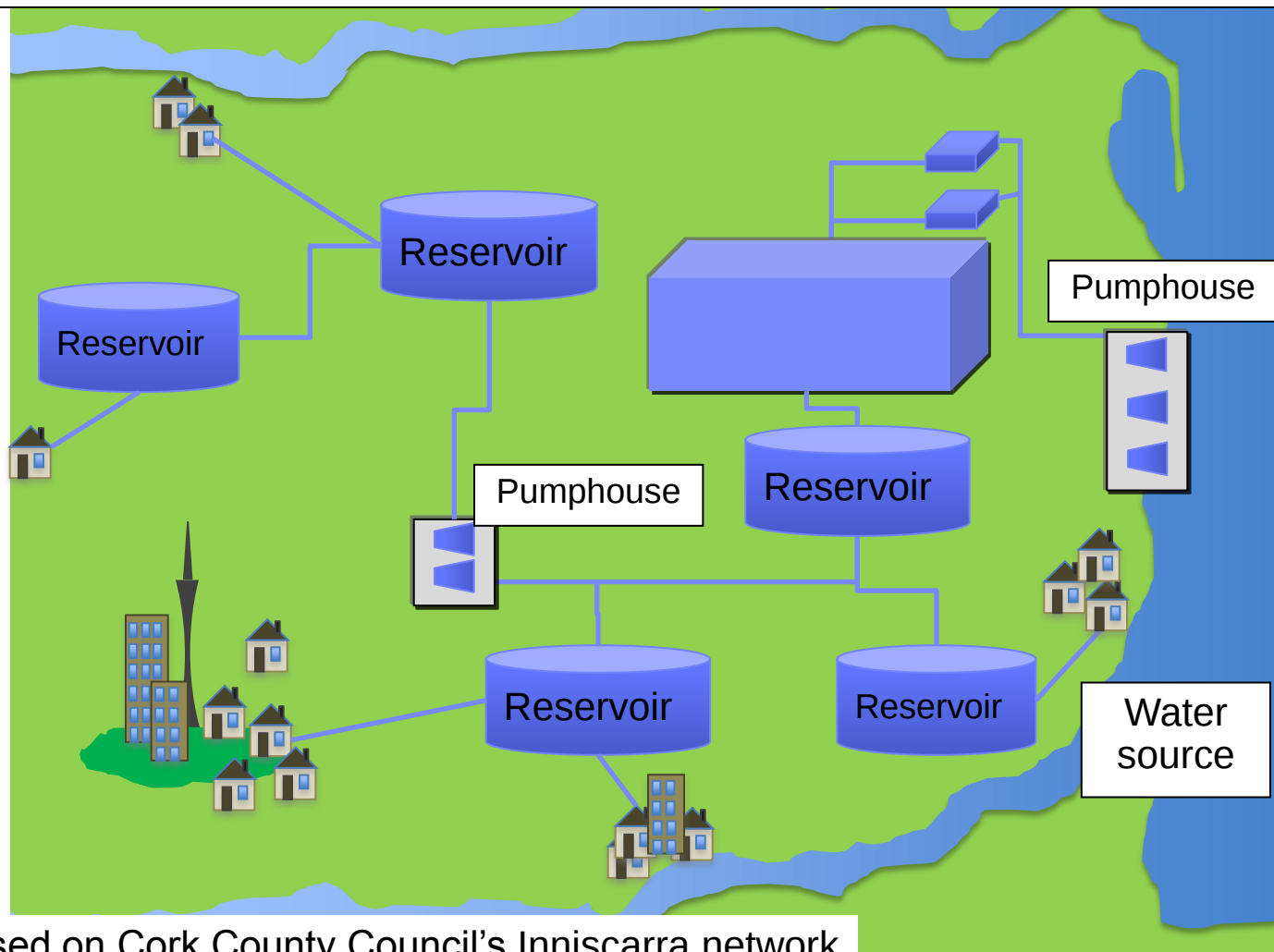
Case study: Water treatment/distribution energy cost reduction

- Big picture: Cork County Council must reduce energy consumption by 20% by 2020
- 95% of this utility's water-related energy costs due to pump operations
- New dynamic energy pricing schemes leverage renewables (wind energy)
- Trade-off: Cleaner energy at lower prices, but uncertainty in price due to
 - Wind uncertainty
 - Network outages
 - Other weather conditions
- Goal: Schedule pumps leveraging dynamic prices, while hedging against uncertainty in price prediction



Simplified network (illustration purposes)

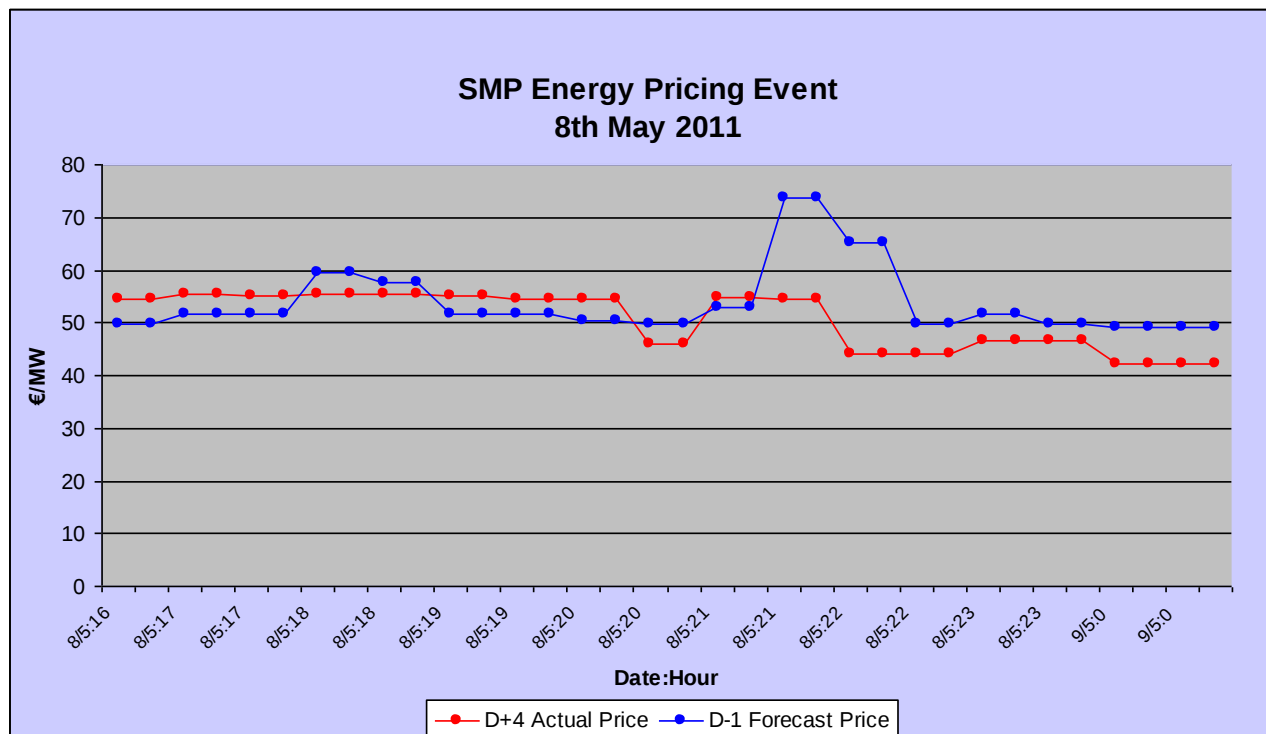
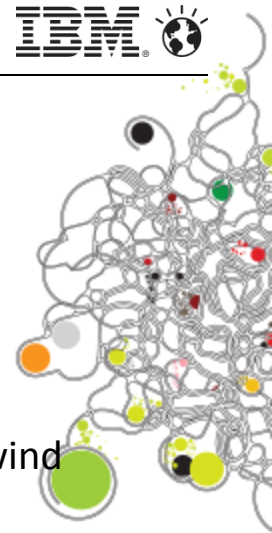
Goal: Optimize pump schedules to minimize (uncertain) energy costs while meeting demand and respecting plant and network constraints*



* Based on Cork County Council's Inniscarra network

Uncertainty in price prediction

- Forecasted (D-1) post ante price from supplier
 - Considers forecasted demand based on weather, special events, wind, etc.
- Actual (D+4) price charged 4 days after the event
 - Forecasted (D-1) and Settled price (D+4) can differ due to changes in predicted wind energy availability, weather, and unpredicted grid events



Question:

Should utility switch to a dynamic pricing scheme?

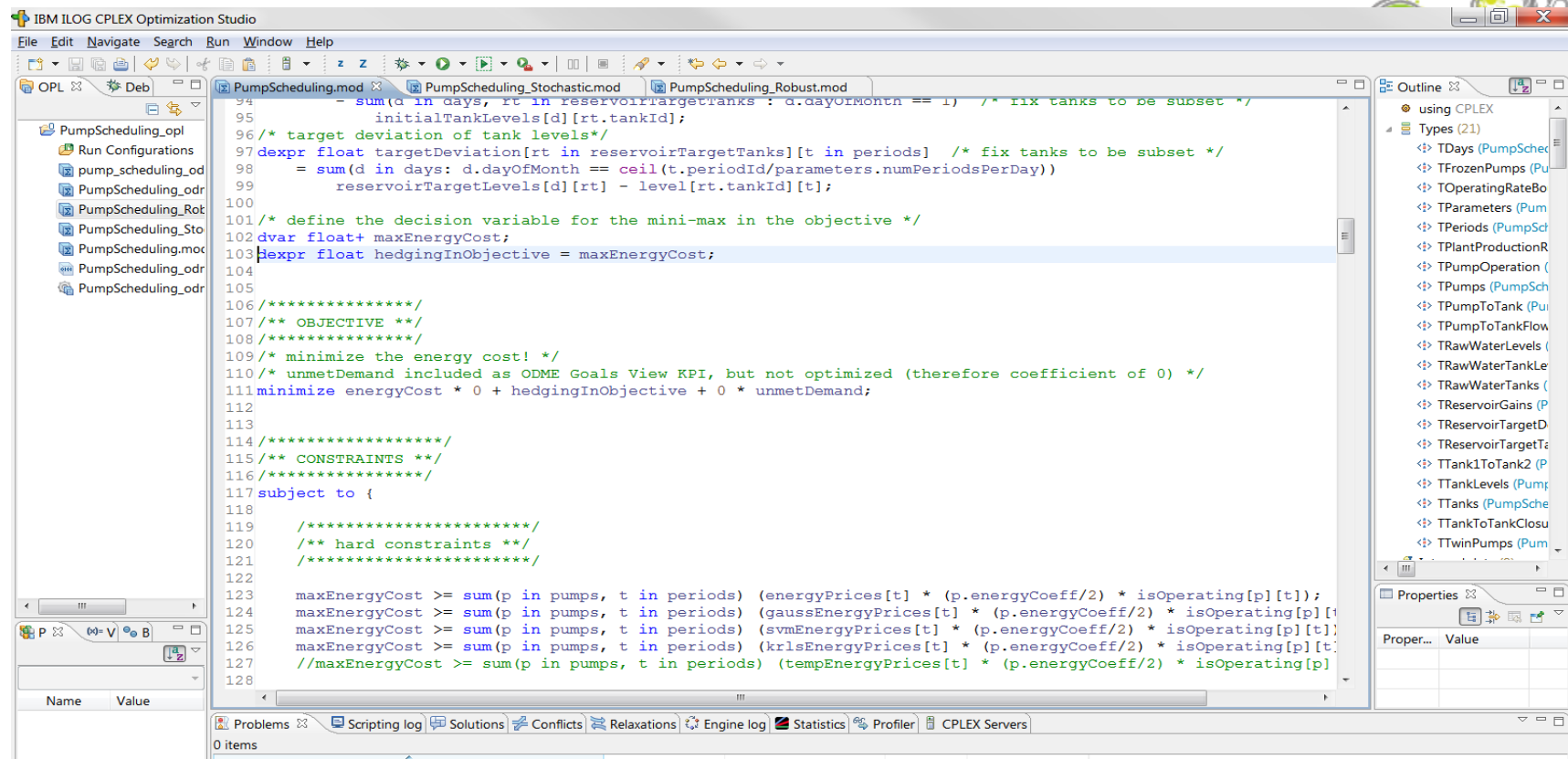
Step 1: Prove dynamic pricing benefits

Step 2: Prove optimization benefits

Step 3: Deal with uncertainty

Step 1: Define decision model

- Define objective, decisions, constraints (mathematical modeling skill required)
 - Objective: minimize energy costs from pump operations
 - Decisions: when to switch pumps on/off (decided every 30 minutes for 24 hours in advance)
 - Constraints: satisfy tank levels, pump operation rules, customer demand, network constraints
- Model using CPLEX Studio, assuming certain data (“deterministic” model)

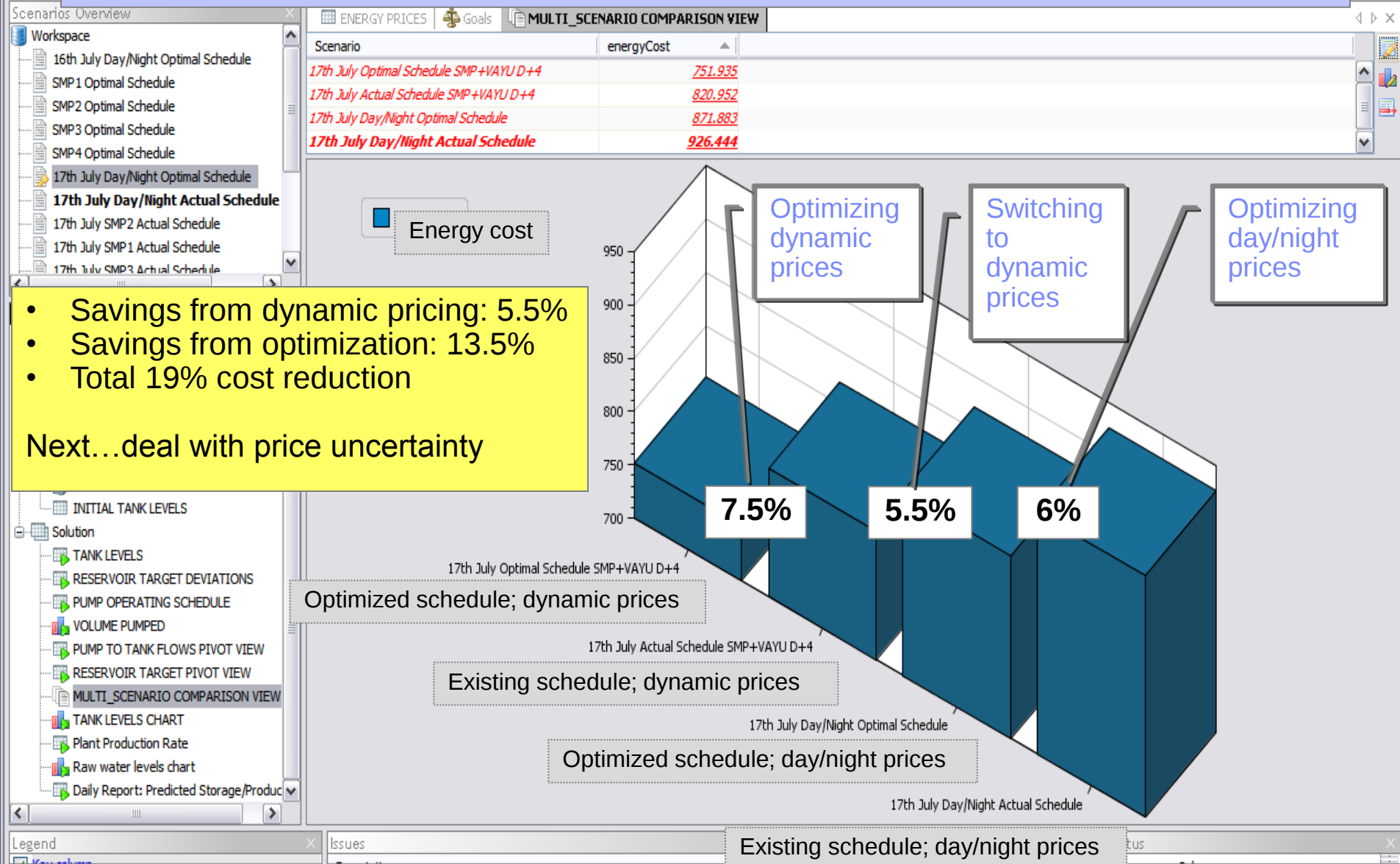


The screenshot displays the IBM ILOG CPLEX Optimization Studio interface. The main window shows a CPLEX model named 'PumpScheduling.mod'. The model is written in CPLEX LP syntax and includes the following key sections:

```

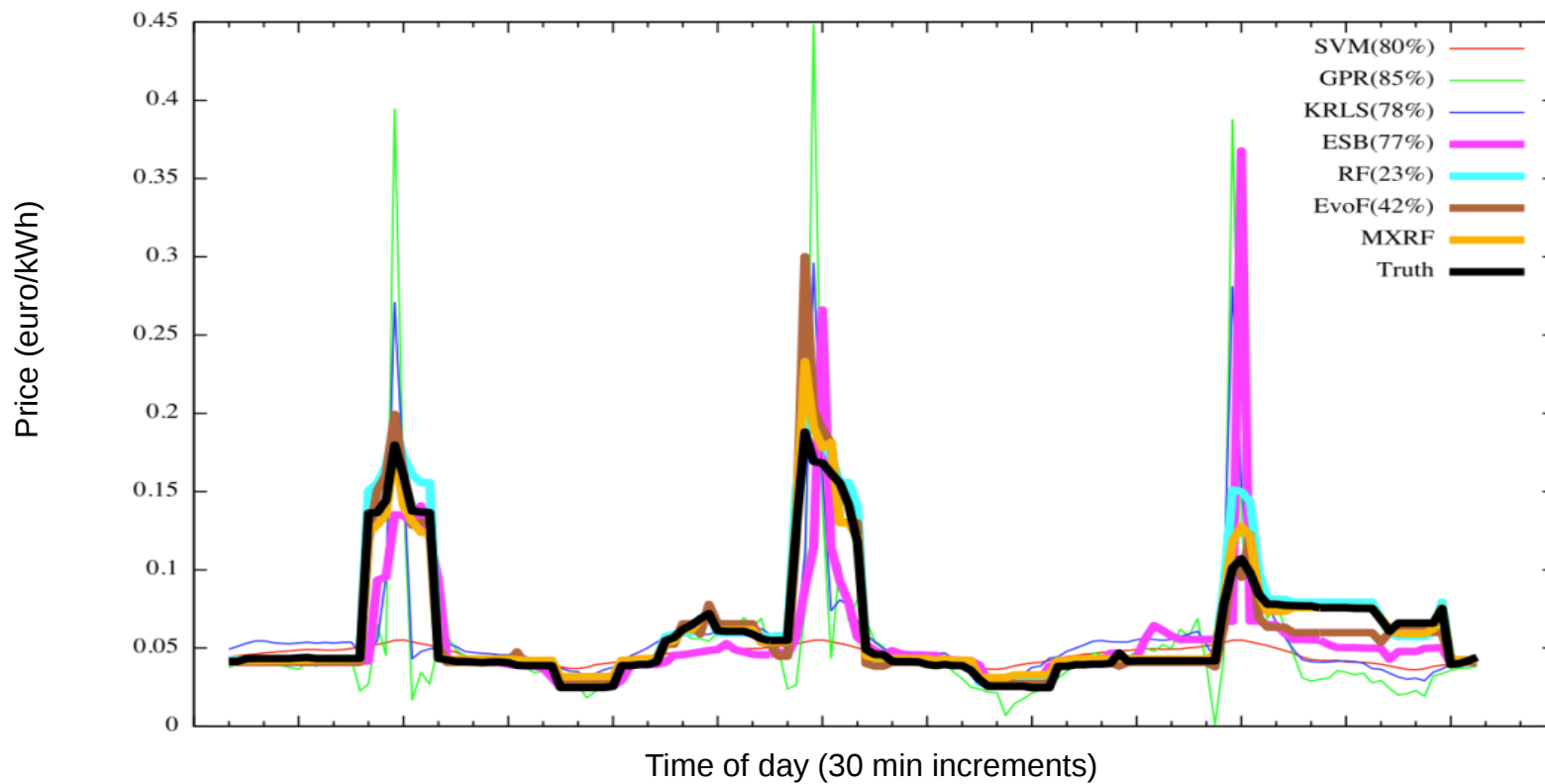
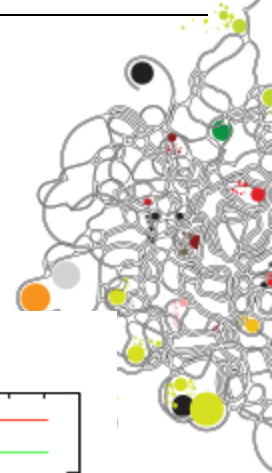
94  - sum(d in days, rt in ReservoirTargetRanks : d.dayOrMonth == 1) /* fix tanks to be subset */
95      initialTankLevels[d][rt.tankId];
96  /* target deviation of tank levels */
97  dexpr float targetDeviation[rt in reservoirTargetTanks][t in periods] /* fix tanks to be subset */
98      = sum(d in days: d.dayOfMonth == ceil(t.periodId/parameters.numPeriodsPerDay))
99      reservoirTargetLevels[d][rt] - level[rt.tankId][t];
100
101 /* define the decision variable for the mini-max in the objective */
102 dvar float+ maxEnergyCost;
103 dexpr float hedgingInObjective = maxEnergyCost;
104
105
106 /*****
107  ** OBJECTIVE **
108  *****/
109 /* minimize the energy cost! */
110 /* unmetDemand included as ODME Goals View KPI, but not optimized (therefore coefficient of 0) */
111 minimize energyCost * 0 + hedgingInObjective + 0 * unmetDemand;
112
113
114 /*****
115  ** CONSTRAINTS **
116  *****/
117 subject to {
118
119      /*****
120      ** hard constraints **
121      *****/
122
123      maxEnergyCost >= sum(p in pumps, t in periods) (energyPrices[t] * (p.energyCoeff/2) * isOperating[p][t]);
124      maxEnergyCost >= sum(p in pumps, t in periods) (gaussEnergyPrices[t] * (p.energyCoeff/2) * isOperating[p][t]);
125      maxEnergyCost >= sum(p in pumps, t in periods) (svmEnergyPrices[t] * (p.energyCoeff/2) * isOperating[p][t]);
126      maxEnergyCost >= sum(p in pumps, t in periods) (krlsEnergyPrices[t] * (p.energyCoeff/2) * isOperating[p][t]);
127      //maxEnergyCost >= sum(p in pumps, t in periods) (tempEnergyPrices[t] * (p.energyCoeff/2) * isOperating[p][t]);
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Decision model in **Decision Optimization Center prototype:** Predicted energy cost savings from pump optimization and (known) dynamic energy prices



Step 2: Characterize uncertainty

- Price scenarios, with likelihoods:
 - From energy provider
 - From IBM Research forecasts



Step 2: Uncertainty Toolkit wizard for consultant input (1 of 2)

Uncertainty Toolkit: recipe manager

Select uncertain data items

Available data items

- AVG_COST_BY_PERIOD
- AVG_COST_BY_UNIT
- FROZEN_IN_USE
- IN_USE
- MAINTENANCE_RULES
- PROD_RULES
- RUN_RULES
- TURN_OFF_RULES
- PLANTS_ONLINE
- METERS
- PERIODS
- PRODUCTION
- RCTable_Maintenance Rule
- RCTable_Max Time in Use
- RCTable_Must Run Rules
- RCTable_Must Turn Off Rules

Uncertain data items

LOADS

Add >

< Remove

<< Clear

Back Next Finish Cancel

1. Select uncertain data

Uncertainty Toolkit: recipe manager

Select uncertain type

Select whether the uncertainty is captured as a data range, or by using discrete input data scenarios.

☒ Scenarios (discrete)

☐ ODME scenarios

☐ Extract from SPSS

☐ Range

Back Next Finish Cancel

2. Select data scenarios vs. ranges

Uncertainty Toolkit: recipe manager

Select risk measures to optimize

Use Optimize

☒ Expected value

☐ Worst-case outcome

☐ CVaR

Back Next Finish Cancel

4. Select risk measures

Uncertainty Toolkit: recipe manager

Define decision stages

How many decision stages are present in the model? For help on deciding on the number of stages, click the icon on the right

2

InUse	1
Production	2
TurnOn	1
TurnOff	1
SpinningCapacityTotal	2
ProductionTotal	2
SpinningReserveTotal	2

Back Next Finish Cancel

3. Define decision stages

Step 2: Uncertainty Toolkit wizard for consultant input (2 of 2)

Uncertainty Toolkit: recipe manager

Constraints should be

☐ Feasible for all scenarios

☒ Allowed to violate

Select all constraint may violate:

- ☒ meet_demand
- ☐ min_generation
- ☐ oper_max_generation
- ☐ max_generation
- ☐ init_ramp_up
- ☐ init_ramp_down
- ☐ ramp_up
- ☐ ramp_down
- ☐ min_up

5. Specify constraint satisfaction

Back Next Finish Cancel

Uncertainty Toolkit: recipe manager

KPI Selection

Configure the KPIs to evaluate in this recipe

KPI #1: OBJECTIVE_VALUE

Objective Value ☒ min problem?

KPI.ObjVar

KPI #2: INFEASIBILITY_MEASURE

Infeasibility Measure

KPI.ExpectedInf

KPI #3: OTHER

SpinningTotal ☐ min problem?

SpinningTotal

6. Define KPIs

Back Next Finish Cancel

Uncertainty Toolkit: recipe manager

Recipe Manager

Open recipes folder

Reload recipes list

Recipe availables

	Name	Description	Open	Delete
2014/03/13 11:31	Bental	new approach	Open	Delete
2014/03/13 11:27	Deterministic	simple cross comparison	Open	Delete
2014/03/13 11:29	Deterministic	with 7 KPIs	Open	Delete
2014/03/13 11:29	Extreme Scenario	description	Open	Delete
2014/03/19 15:39	recipe	description	Open	Delete
2014/03/19 15:54	recipe	description	Open	Delete
2014/03/11 15:23	Robust	Mulvey approach with 2+...	Open	Delete
2014/03/13 11:31	Stochastic 3	CVar	Open	Delete
2014/03/13 11:28	Stochastic Mulvey	mixed recipe	Open	Delete
2014/03/11 14:29	Stochastic	With 2 + 3 kpis	Open	Delete
2014/03/13 11:31	Stochastic	Worst case opt	Open	Delete

8. Save your recipe for later use

Back Next Finish Cancel

Uncertainty Toolkit: recipe manager

Is there any strong correlation between the parameters?

☒ Yes, take correlation into account

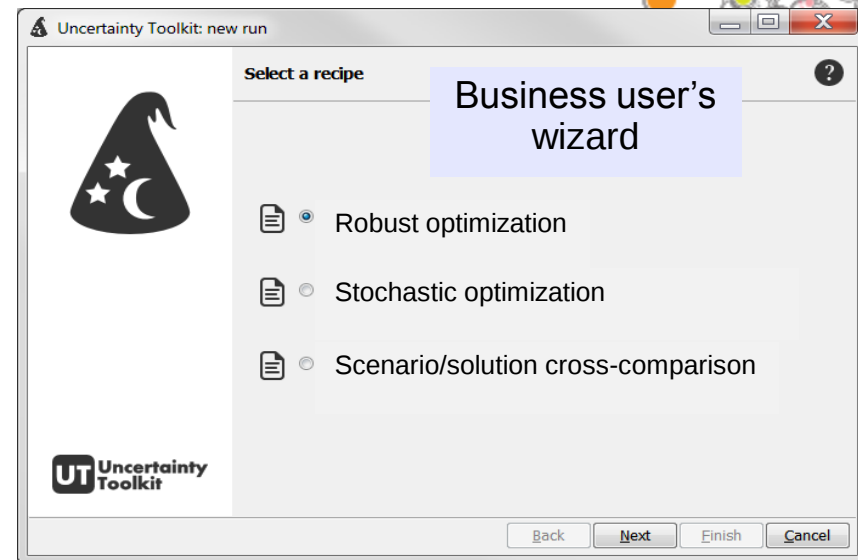
☐ No, allocate budget of uncertainty (across uncertain parameters)

7. Define correlation (optional)

Back Next Finish Cancel

Step 3: Generate uncertain model

- Uncertainty Toolkit automatically generates the uncertain model(s) depending on choices in Steps 1 and 2
- Uncertain models are typically classified as
 - “Robust”: hedging against worst case outcome(s)
 - “Stochastic”: optimizing for expected outcome(s)
 - If choice unclear, use both & visualize trade-offs



Step 4: Generate plans

- Uncertainty Toolkit generates multiple solutions (deterministic, robust, stochastic)
- Uncertainty Toolkit automatically does solution-scenario cross-comparison
 - What is the impact of change on each plan

Automated plan generation for varying scenarios

Reduced risk due to stochastic / robust solutions

Plan comparison across scenarios

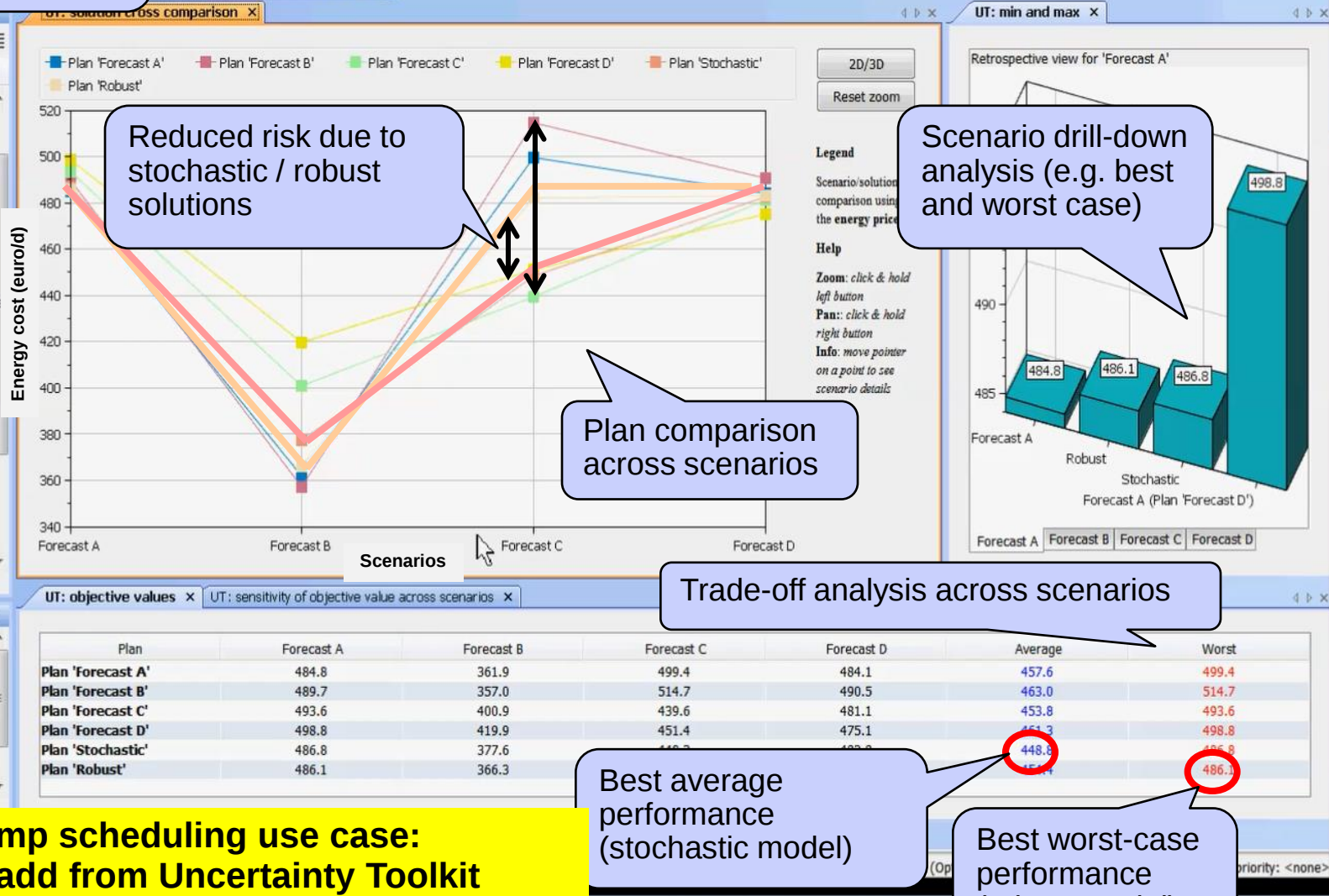
Scenario drill-down analysis (e.g. best and worst case)

Trade-off analysis across scenarios

**Pump scheduling use case:
Value-add from Uncertainty Toolkit
~ 30% improvement in energy cost reduction**

Best average performance (stochastic model)

Best worst-case performance (robust model)

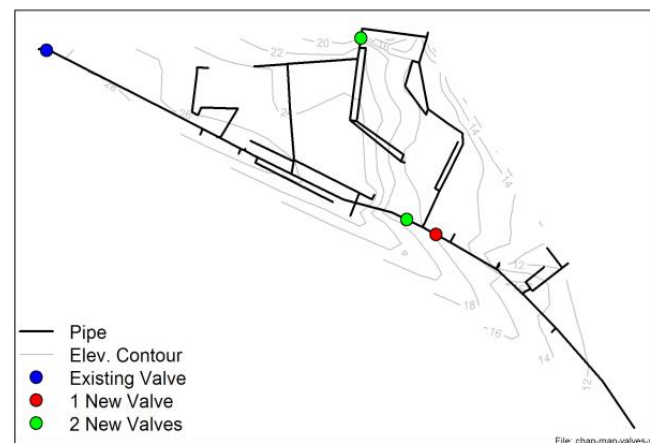


Example: pressure management in water distribution networks

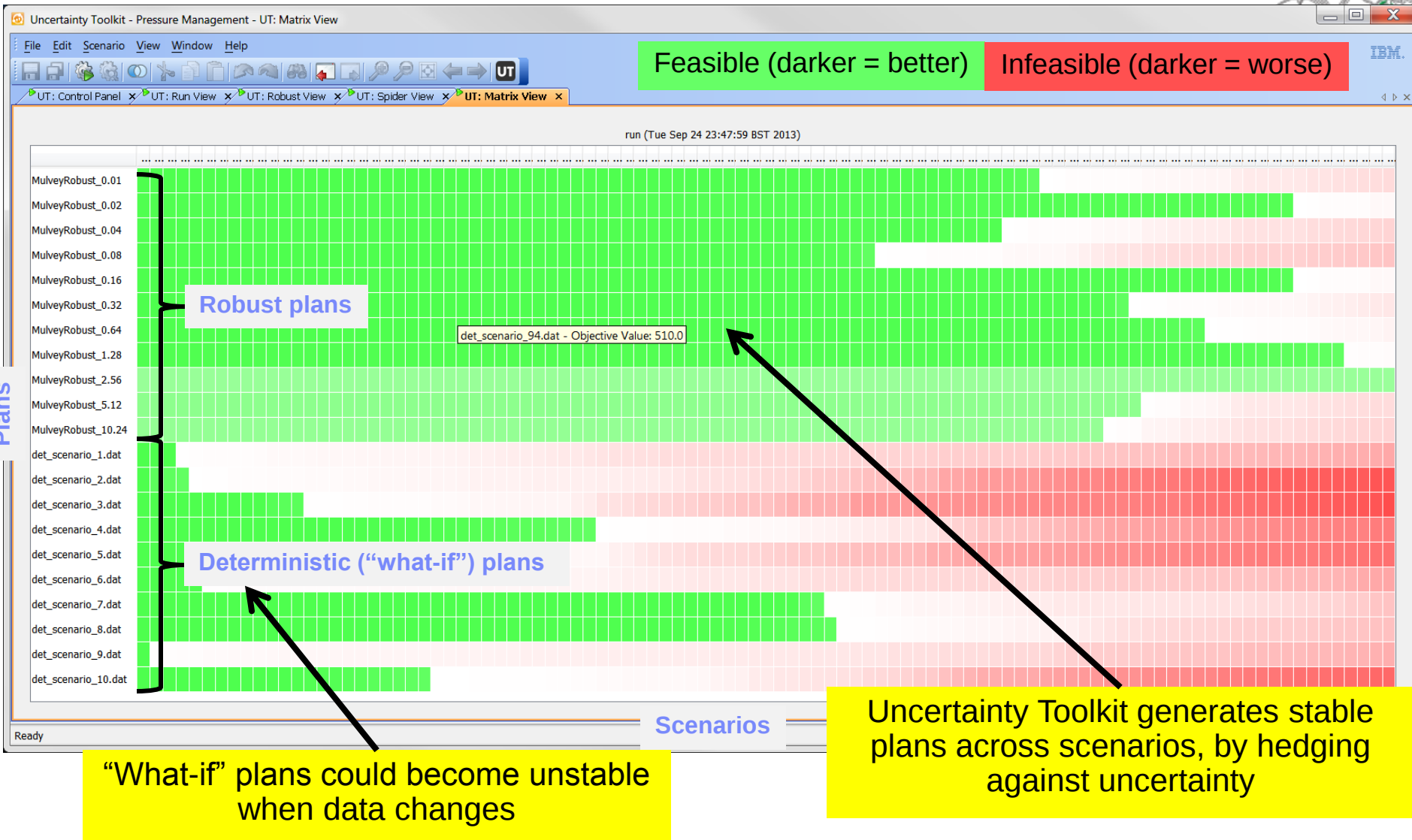
- Problem: Leakage (non-revenue water) leads to 5 – 60% of treated water lost
- Existing solution:
 - 1% pressure reduction ~ 1% leakage reduction
 - Place and set pressure reducing valves to minimize leakage for given demand pattern (deterministic plans)
- New challenge: demand uncertain
 - Unexpected short large draw-offs by industrials
 - Variations depending on time of day / week
 - Deterministic plans not robust – often infeasible & sub-optimal when demand changes
- Uncertainty Toolkit creates robust plans
 - Stable (robust) valve settings / placement (no need for frequent changes as demand changes)
 - Leakage reduction across demand scenarios



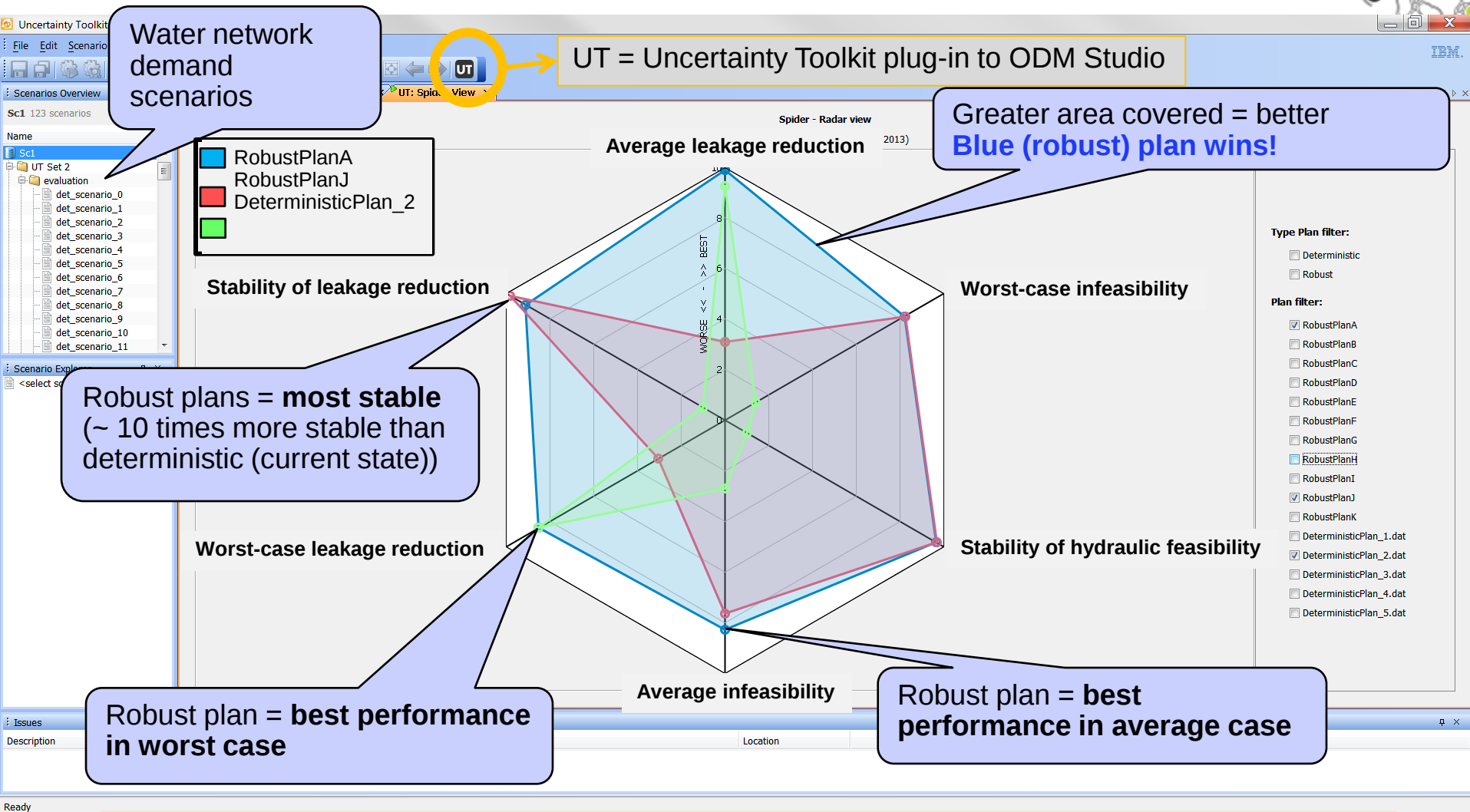
Dublin's Chapelizod network:
optimal robust valve placement



Benefits of Uncertainty Toolkit – pressure management use case



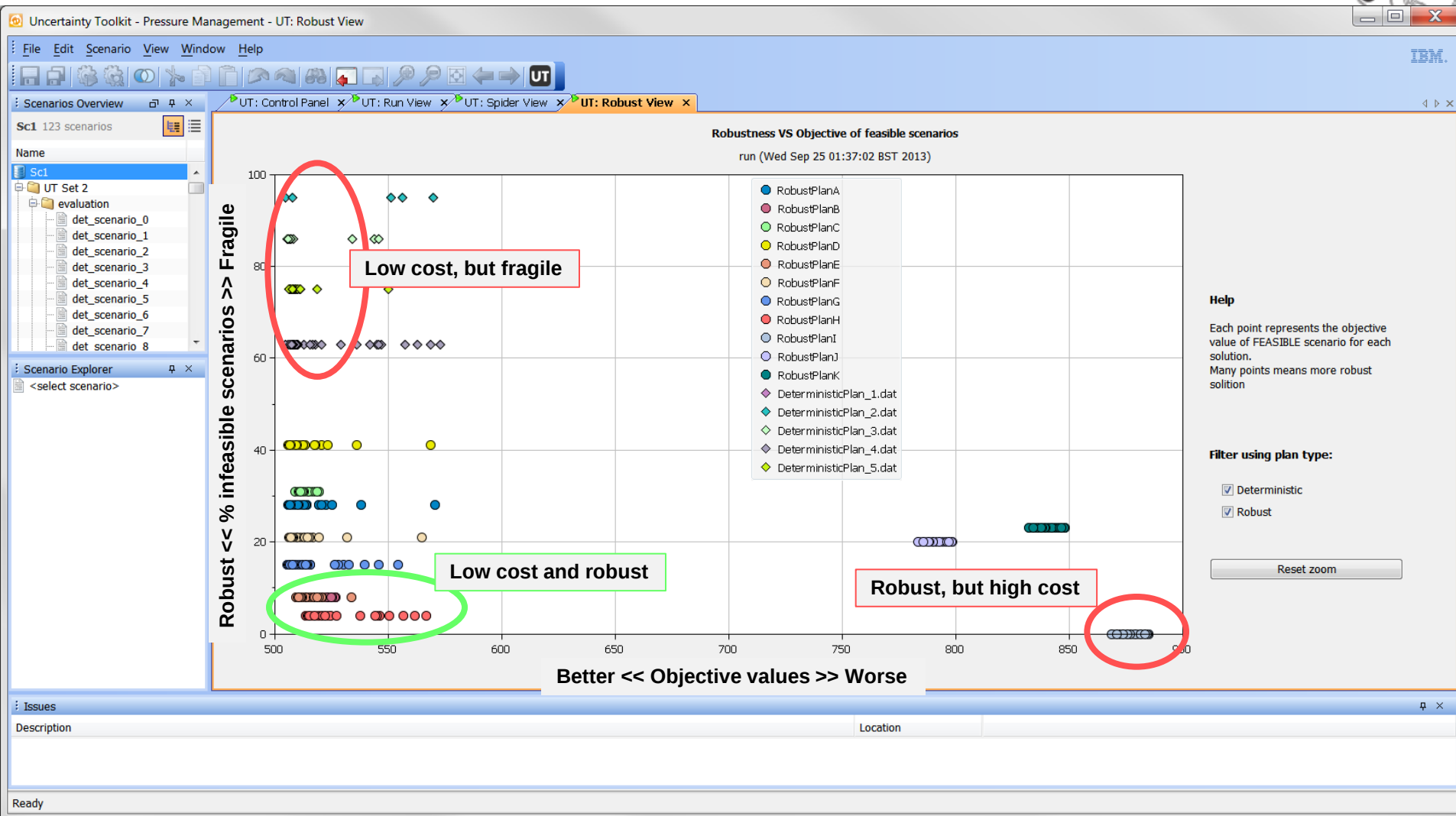
Benefits of Uncertainty Toolkit – pressure management use case



Pressure management use case:
Water network operational decisions 10 times more stable than current state, continue to perform well when data changes (i.e. “robust” plans)

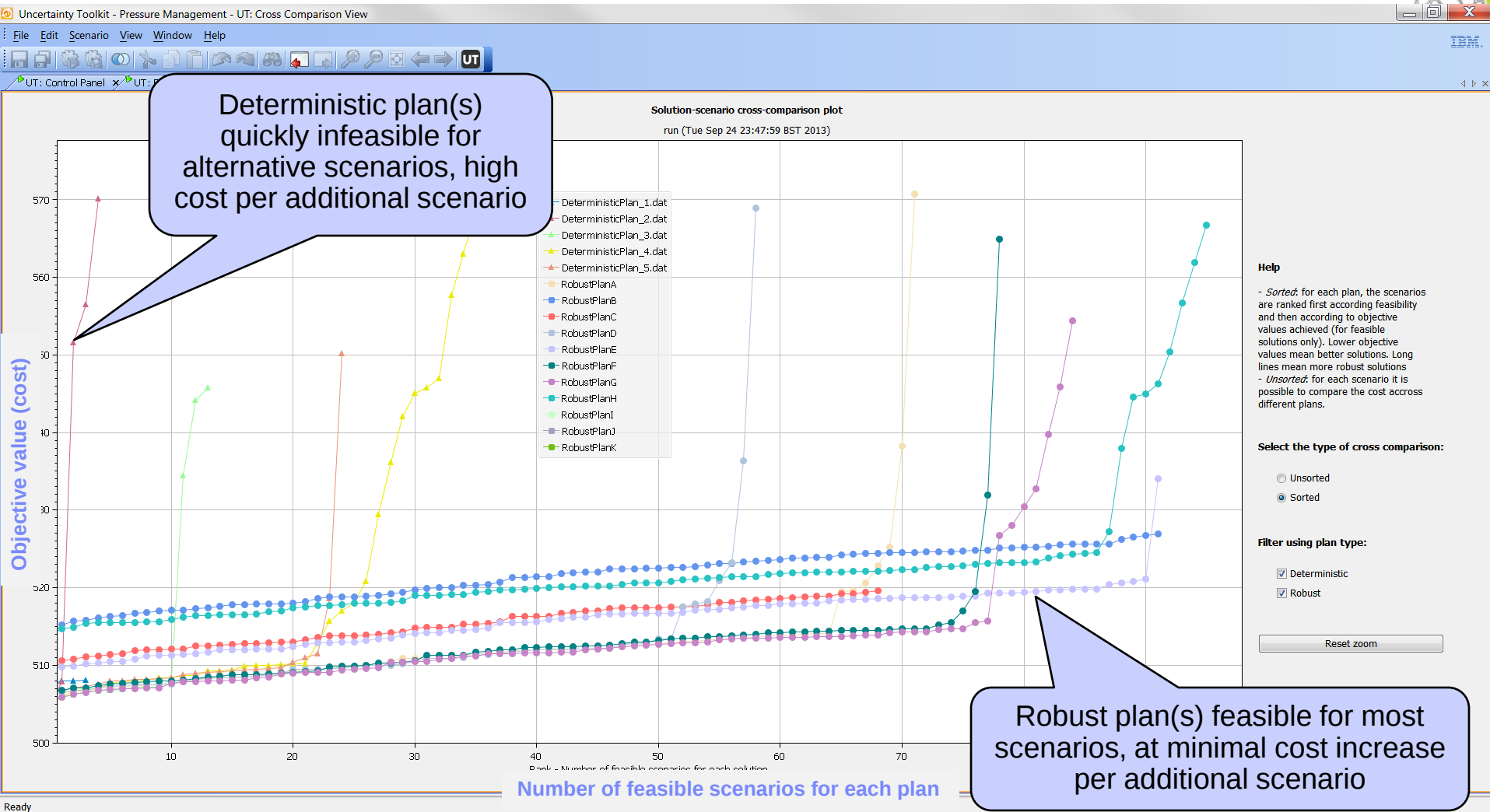
Decision Optimization

Benefits of Uncertainty Toolkit – pressure management use case



Visualization of trade-off: robustness vs. cost

Benefits of Uncertainty Toolkit – pressure management use case

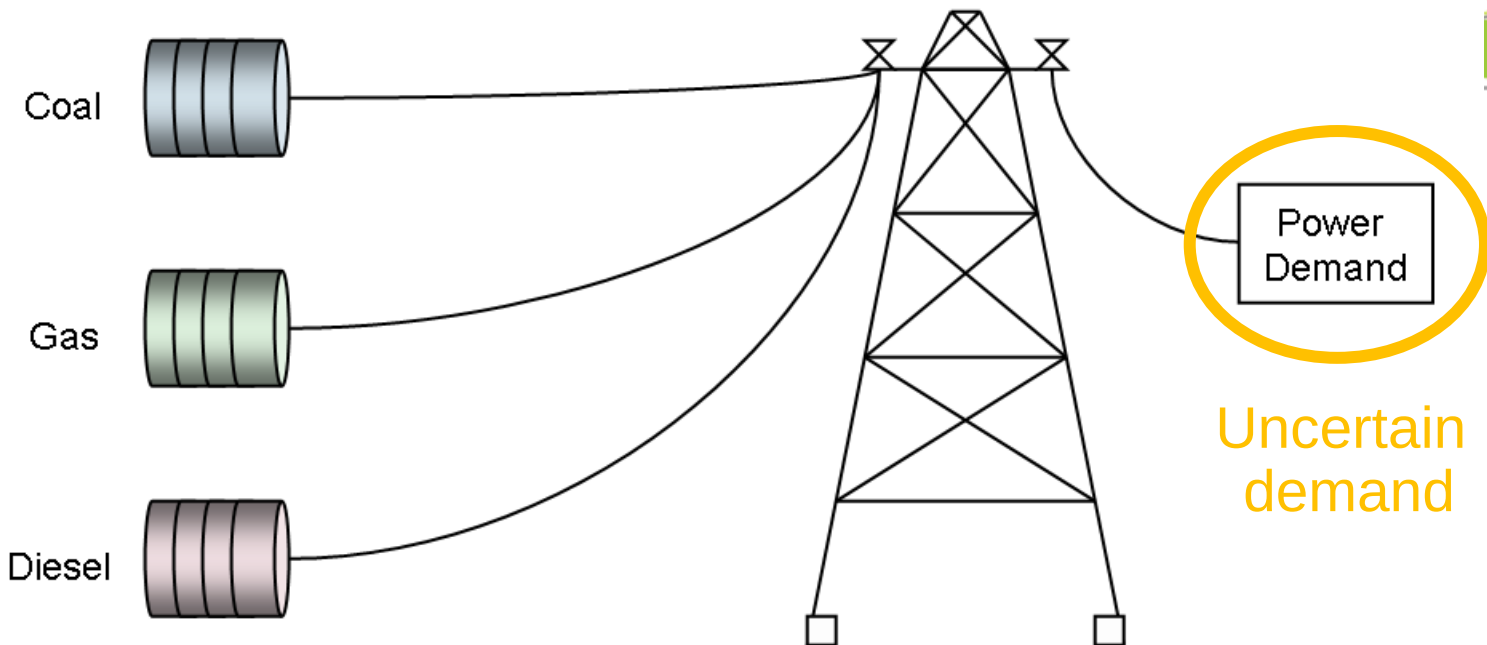


Effect on feasibility (robustness) by increasing cost

Example: Unit Commitment

The Unit Commitment Problem

3 types of power generators (units)



Business goal: Determine production schedule that minimizes startup cost + fuel cost + ecological cost (due to CO₂ emissions), while satisfying demand

Unit Commitment Problem

Given

- Power generation units with
 - Costs (start-up, fuel, CO2)
 - Operational properties (capacity, ramp)
- Demand over several periods

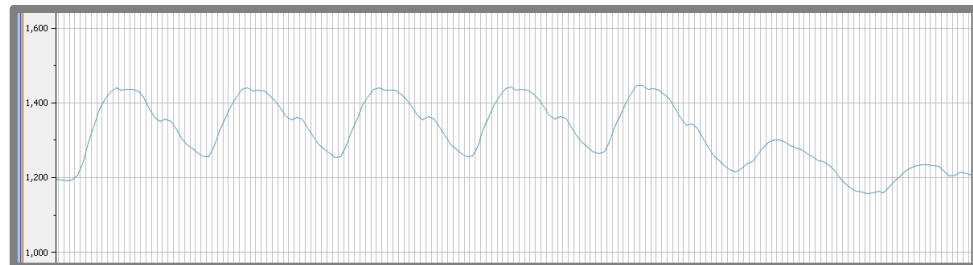
find generation plan

- Which units to use (unit commitment)
- How much to produce (dispatch)

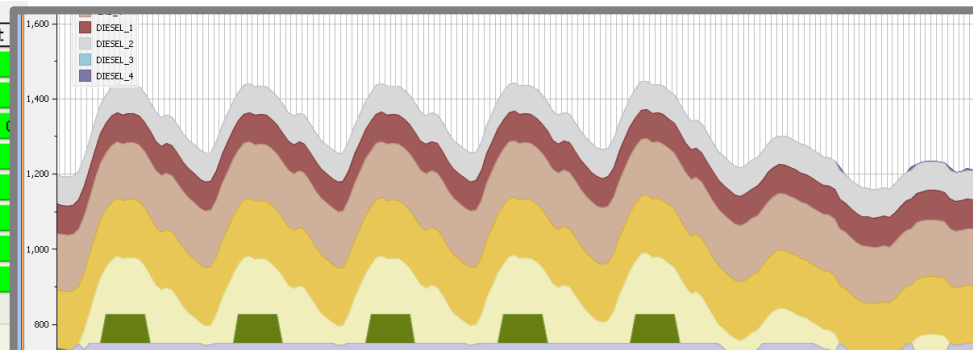
such that

- Demand is satisfied
- Operational constraints are satisfied
- Total cost is minimized

Type	Name	Linear Operations Cost	Fixed Start Up Cost	Linear Start Up Cost	CO2 Cost
Coal	COAL_1	\$22.536	\$5,000	\$208.607	\$30
	COAL_2	\$31.985	\$4,550	\$117.372	\$30
Diesel	DIESEL_1	\$40.222	\$560	\$54.417	\$15
	DIESEL_2	\$40.522	\$554	\$54.551	\$15
	DIESEL_3	\$116.331	\$300	\$79.638	\$15
	DIESEL_4	\$76.642	\$250	\$16.259	\$15
Gas	GAS_1	\$70.5	\$1,320	\$174.117	\$5
	GAS_2	\$69	\$1,291	\$172.754	\$5
	GAS_3	\$32.146	\$1,280	\$95.353	\$5
	GAS_4	\$54.84	\$1,105	\$144.517	\$5



Name	ID	Qty	...	March 2014	...	Wed 12	Thu 13	Fri 14	Sat
COA...	COAL_1	1							
COA...	COAL_2	1							
GAS_1	GAS_1	1	1	AS_1 is c			AS_1 is c		AS_1 is c
GAS_2	GAS_2	1							
GAS_3	GAS_3	1							
GAS_4	GAS_4	1							
DIES...	DIESEL_1	1							
DIES...	DIESEL_2	1							
DIES...	DIESEL_3	1							
DIES...	DIESEL_4	1							



Unit Commitment Problem – Stochastic Version

Problem: How to deal with uncertain loads?

Question:

- Is the dispatch plan still feasible under a slight perturbation of the load?

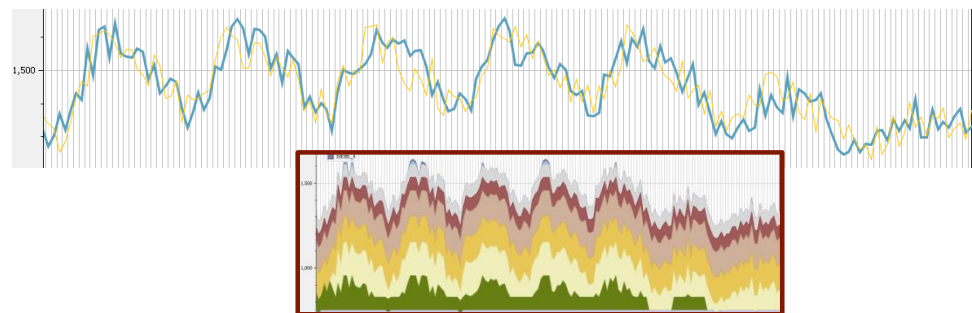
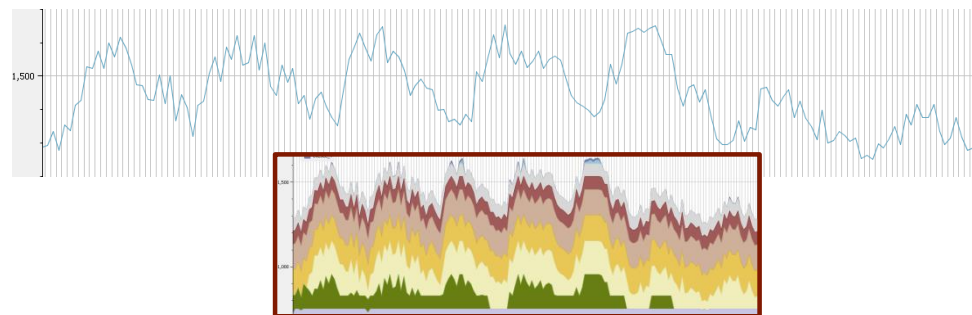
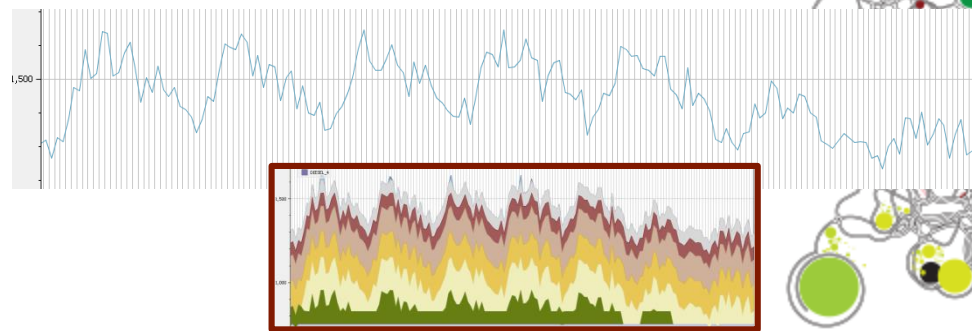
Stochastic Programming Approach

- Separate decisions into stages to be able to “react” to uncertainty

Decision Stages

- Stage 1: **unit commitment**
 - “Here-and-now” decisions
- Stage 2: **dispatch**
 - “Wait-and-see” decisions

Name	ID	Qty	... March 2014			
			... Wed 12	Thu 13	Fri 14	Sat 15
 COA...	COAL_1	1				
 COA...	COAL_2	1				
 GAS_1	GAS_1	1	1	AS_1 is c	AS_1 is c	AS_1 is c
 GAS_2	GAS_2	1				
 GAS_3	GAS_3	1				
 GAS_4	GAS_4	1				
 DIES...	DIESEL_1	1				
 DIES...	DIESEL_2	1				
 DIES...	DIESEL_3	1				
 DIES...	DIESEL_4	1				



Step 6a: Inspecting the results: Table View

UT: Control Panel x UT: Run View x **UT: Table View** x

Solution-scenario cross-comparison table
anne-stochastic-8scen-random0.1 (Fri Mar 14 00:55:35 CET 2014)

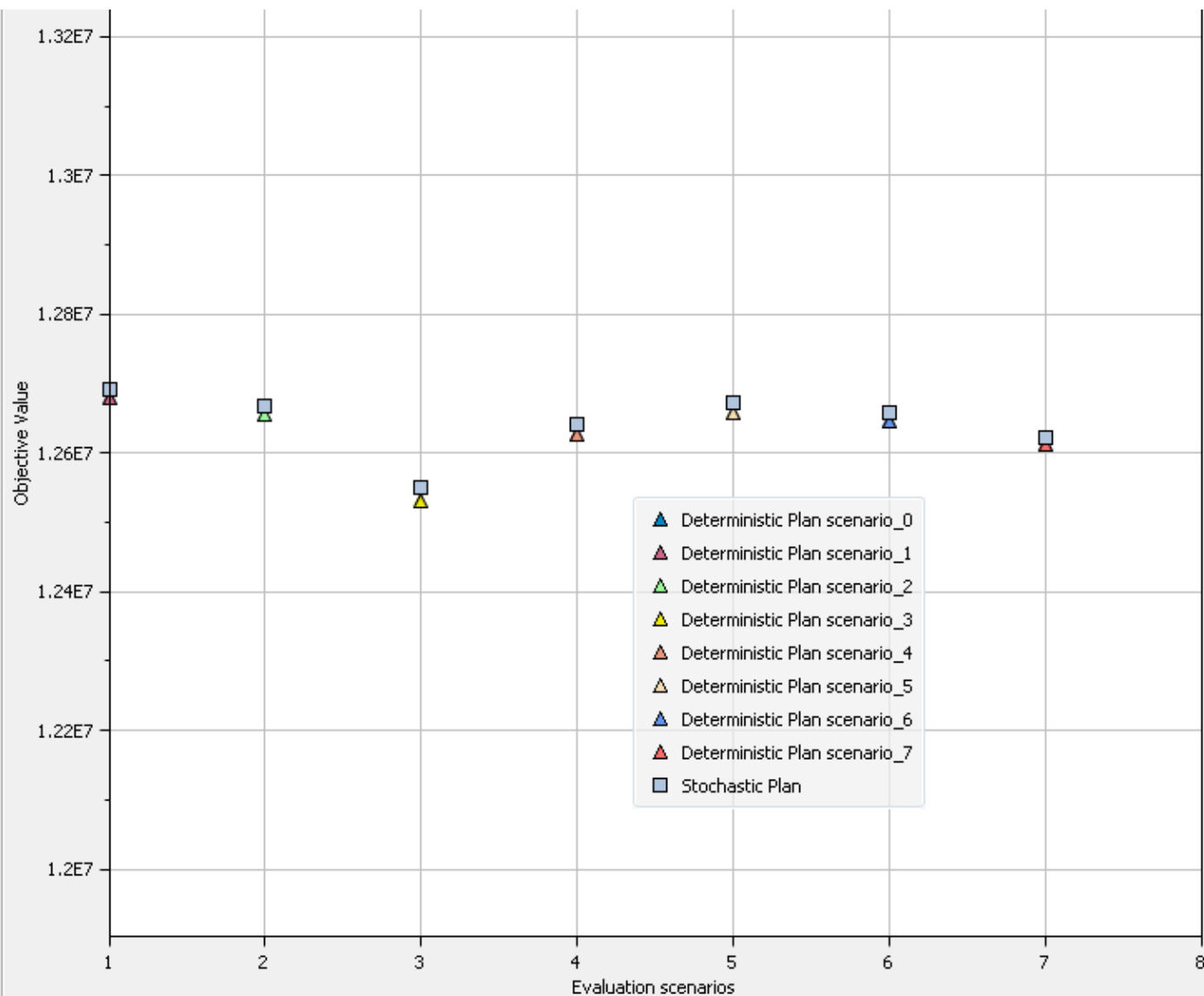
Select the KPI to show:

Table cell width:

	scenario_0	scenario_1	scenario_2	scenario_3	scenario_4	scenario_5	scenario_6	scenario_7
Stochastic Plan	1.261418013E7	1.269088468E7	1.266713216E7	1.25511859E7	1.264070389E7	1.267165055E7	1.265699715E7	1.262302906E7
Deterministic Plan scenario_0	1.260033047E7							
Deterministic Plan scenario_1		1.267959751E7						
Deterministic Plan scenario_2			1.265528409E7					
Deterministic Plan scenario_3				1.253091733E7				
Deterministic Plan scenario_4					1.262720859E7			
Deterministic Plan scenario_5						1.265728358E7		
Deterministic Plan scenario_6							1.264521643E7	
Deterministic Plan scenario_7								1.261238517E7

- Stochastic Plan is feasible for all scenarios
- Deterministic plans are only feasible for “their” scenario

Step 6b: Solution-Scenario Cross-Comparison



Select KPI to display:

Objective Value

Help

Sorted: for each plan, the scenarios are ranked first according to feasibility and then according to objective values achieved (for feasible solutions only). Lower objective values mean better solutions. Long lines mean more robust solutions

Unsorted: for each scenario it is possible to compare the cost across different plans.

Type of cross comparison:

- ☐ Sorted according to performance
- ☒ Sorted according to scenario number

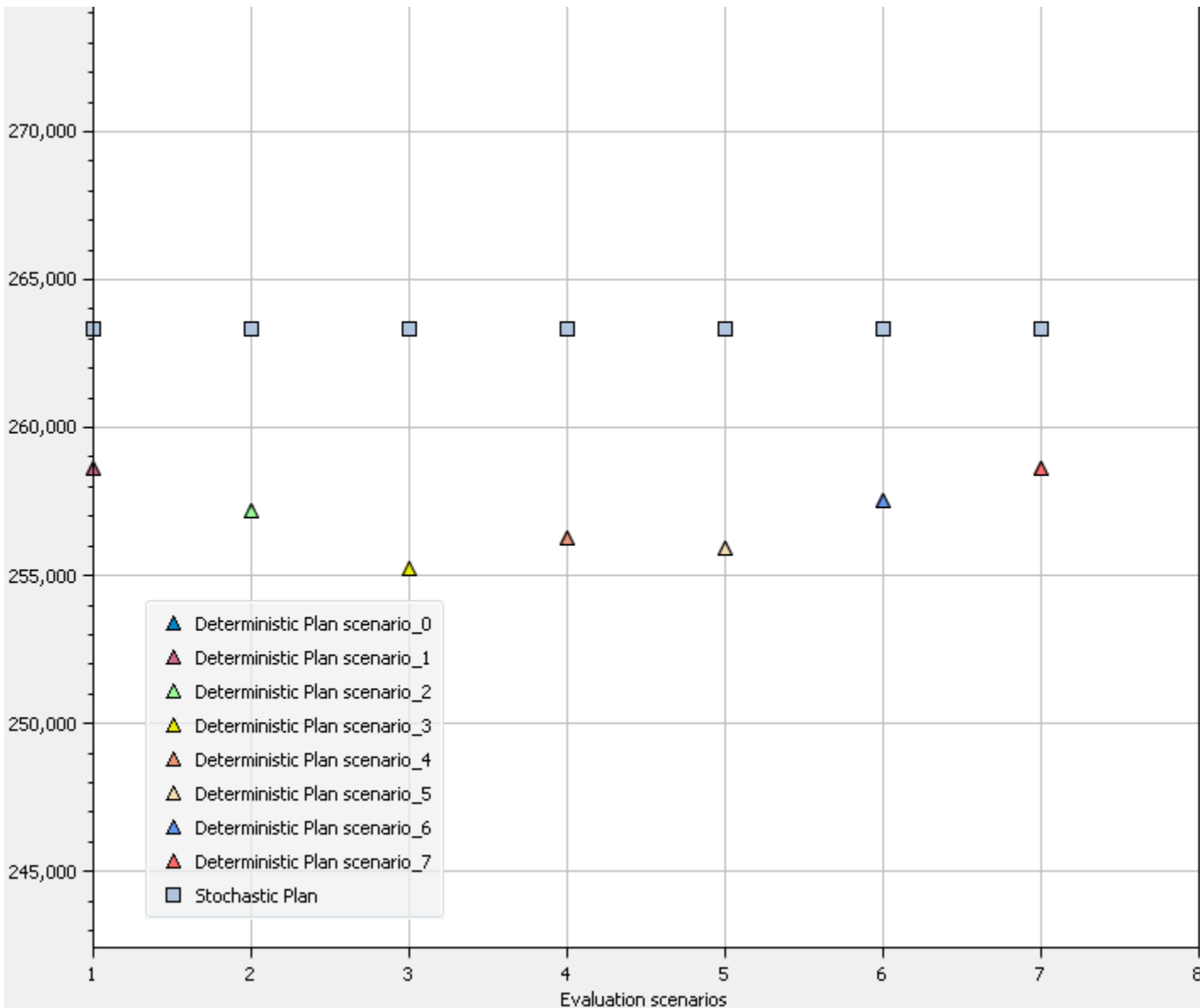
Filter using plan type:

- ☒ Deterministic
- ☒ Robust
- ☒ Stochastic



Reset zoom

Step 6c: Cross-Comparison: Spinning Capacity



Select KPI to display:

SpinningCapacityTotal

Help

Sorted: for each plan, the scenarios are ranked first according feasibility and then according to objective values achieved (for feasible solutions only). Lower objective values mean better solutions. Long lines near more robust solutions

Unsorted: for each scenario it is possible to compare the cost across different plans.

Type of cross comparison:

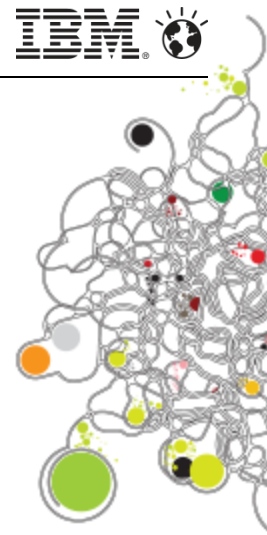
- ☐ Sorted according to performance
- ☒ Sorted according to scenario number

Filter using plan type:

- ☒ Deterministic
- ☒ Robust
- ☒ Stochastic



Reset zoom



References & contact info

■ References

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- J. M. Mulvey, R. J. Vanderbei, and S. A. Zenios, “Robust Optimization of Large-Scale Systems,” *Operations Research*, vol. 43, no. 2, pp. 264-281, 1995.
- A. Ben-Tal and A. Nemirovski, “Robust solutions of uncertain linear programs,” *Operations research letters*, vol. 25, no. 1, pp. 1-13, 1999.
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- C. Lee, “Extreme scenario approach,” forthcoming paper, to be presented at the *International Federation of Operational Research Societies (IFORS) conference*, Barcelona, 2014.
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■ Contact

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