Refinery Optimization

Recent Advances in Planning and Blending Operations

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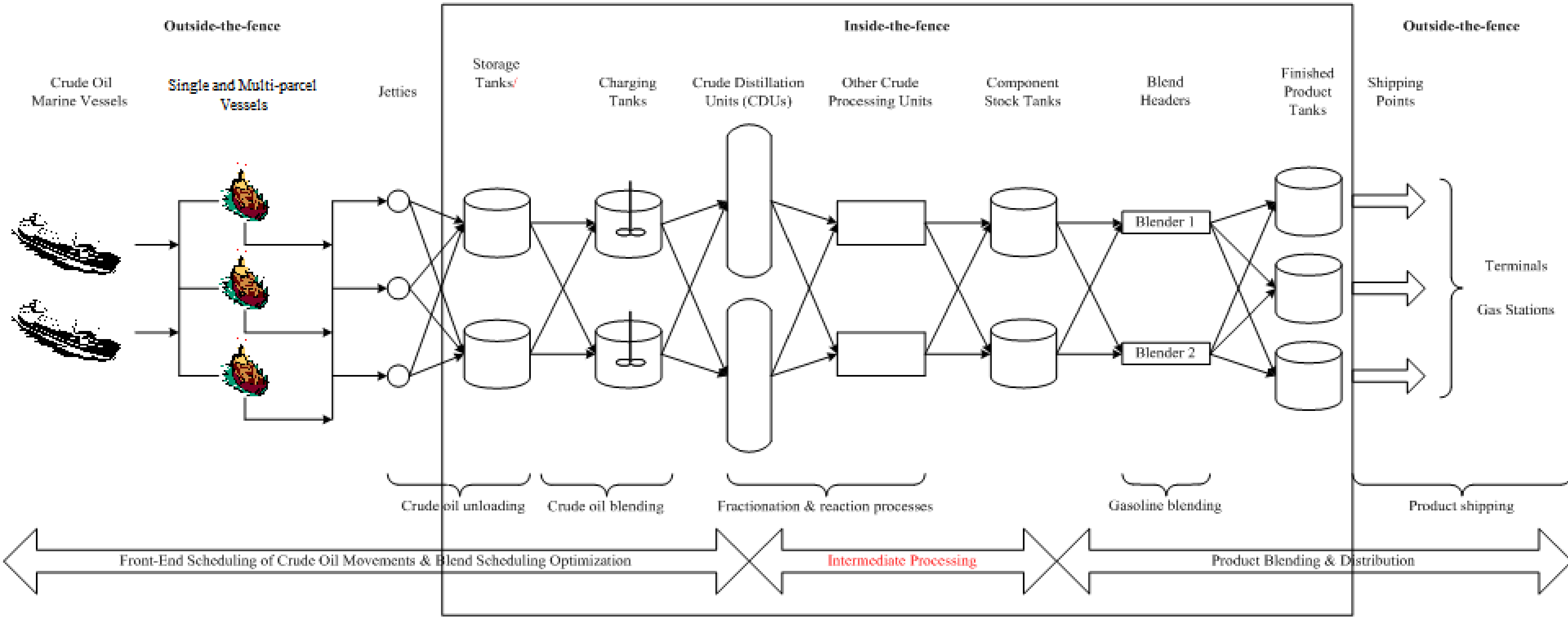
Overview

- Introduction to refinery optimization
- Optimal crude selection and refinery planning
- Product blending optimization
- Conclusions

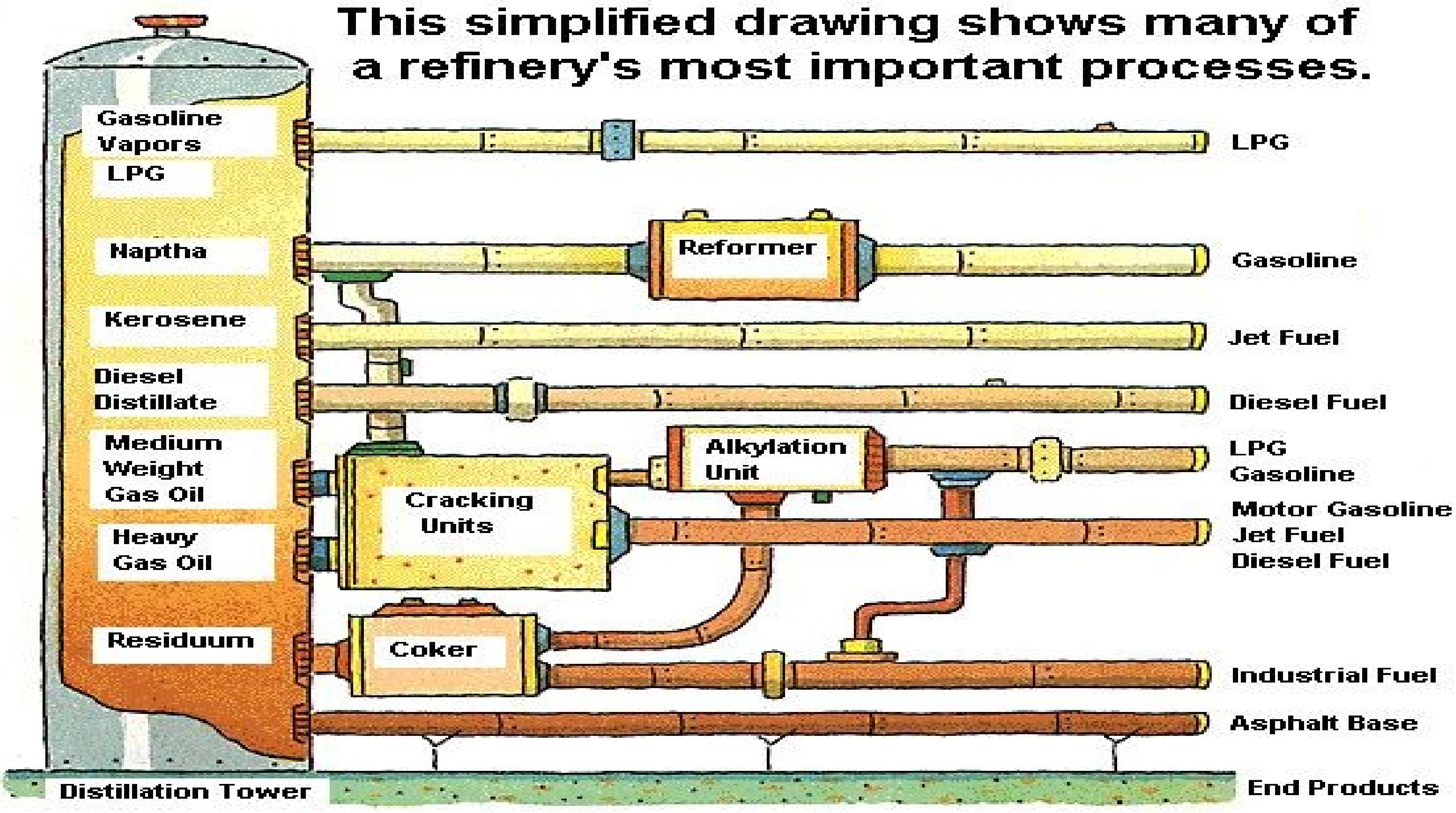
Introduction to Refinery Optimization

- Historical perspective
- Planning, 70s
  - LP → SLP → MINLP
- Advance process control, 80s
  - LP
- Real-time optimization, 90s
  - NLP → SQP
- Blending and scheduling, 90s
  - NLP → MINLP
- Supply chain, 90s
  - MILP

Petroleum Supply Chain Scope



Refining Process



Definition and Motivation

- Refinery Planning is a Work Process that involves multi-period, nonlinear optimization, including discrete decisions
- Goal is to decide the optimal set of crudes to be purchased
  - Crude valuation
  - Demand affects price and availability
  - Optimization horizon 2 – 6 months
- This process is enhanced by numerous ad-hoc scenario evaluations
  - Price scenarios
  - Unit availability scenarios
- There is no comprehensive framework that will:
  - Analyze the nonlinear solution space for decision variables
  - Consider multiple objectives
  - Ensure a global solution in terms of math programming

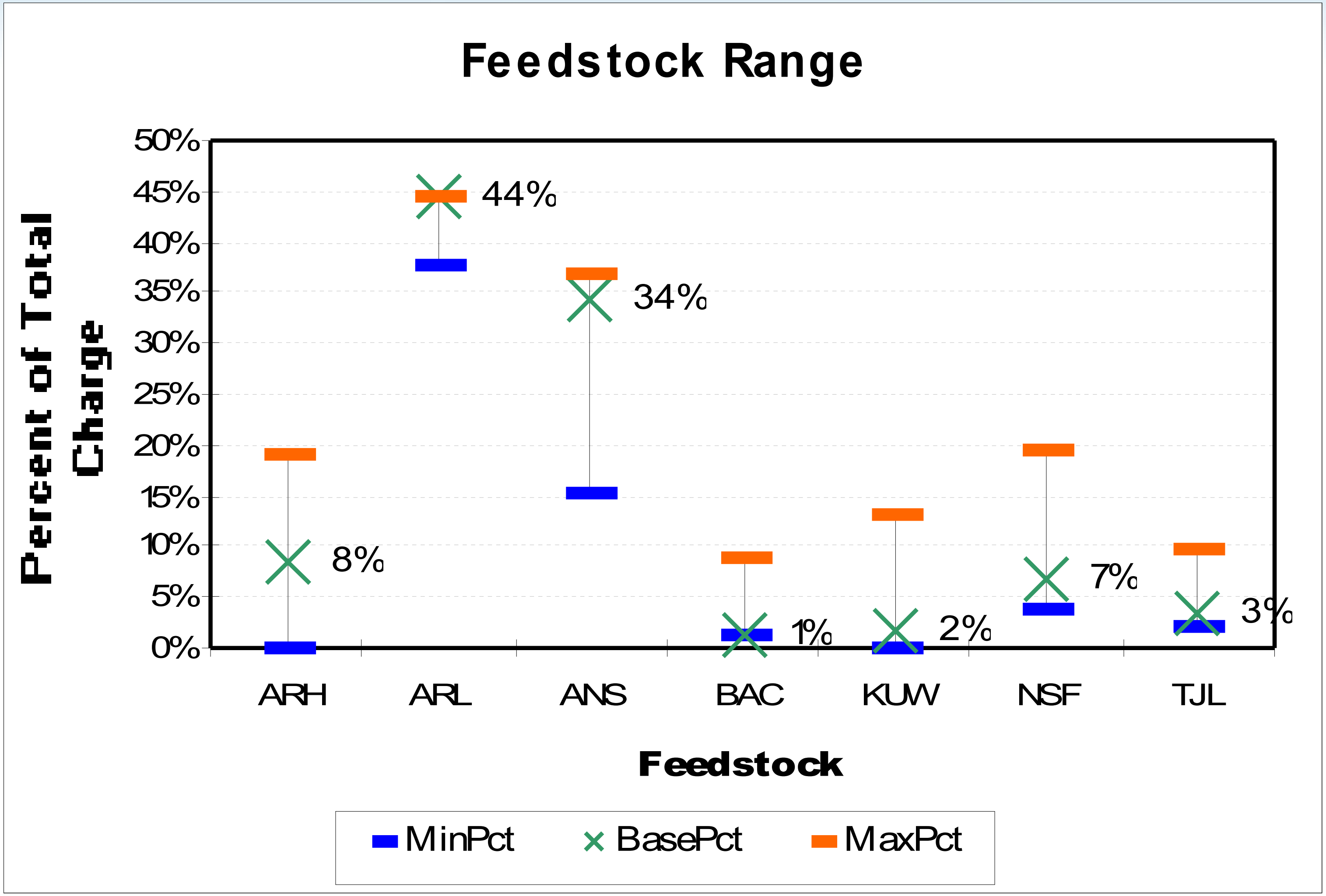
New Planning Process Highlights

- A new comprehensive way to integrate, expand, and analyze the optimization solution of a refinery planning model in the context of a complex business decision making process
- Introduce rigorous and automated analysis that identify optimal feedstock ranges
- Incorporate goal programming into the daily planning work process
- Provide a complete global optimization framework that includes stochastic and deterministic elements

Optimal Solution Range Analysis

- Explores the non-linear surface of the optimal planning solution
- Identifies a range of values for key decision variables such as feed stocks and products
- Provides two indices per variable
- Minimize / Maximize feedstock based on nominal optimality relaxation (typically 0.1%)

Solution Range Analysis



Optimal feed stock ranges for seven different crudes in a typical US refinery

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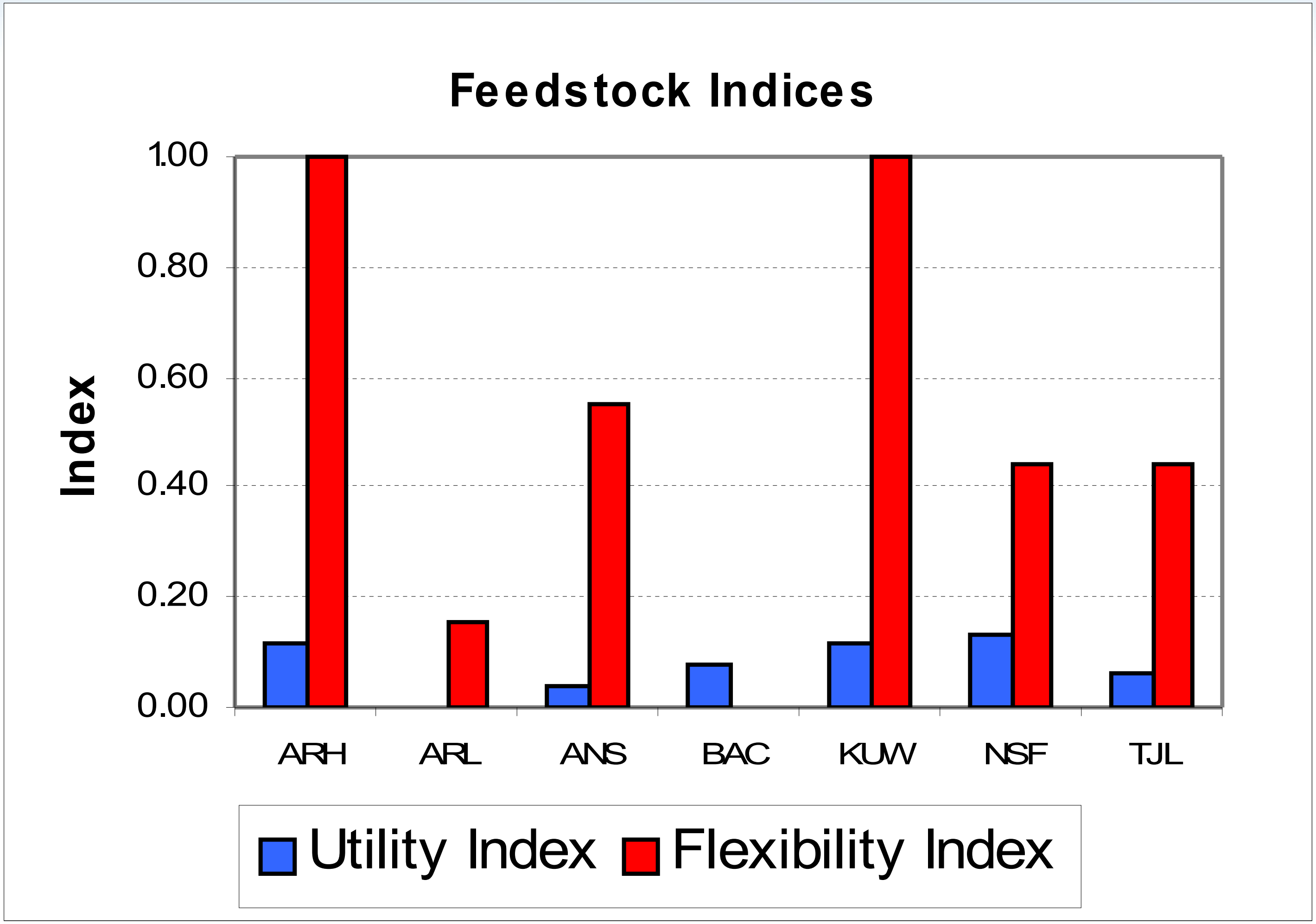
Flexibility and Utility Indices



Flexibility and Utility index for seven different crudes in a typical US refinery

Solution Range Benefits

- Improved profitability (Trading)
  - Enhanced crude valuation
- Improved flexibility (Operations)
  - Scheduling insight
- Better understanding of the solution space
- Better risk management capability

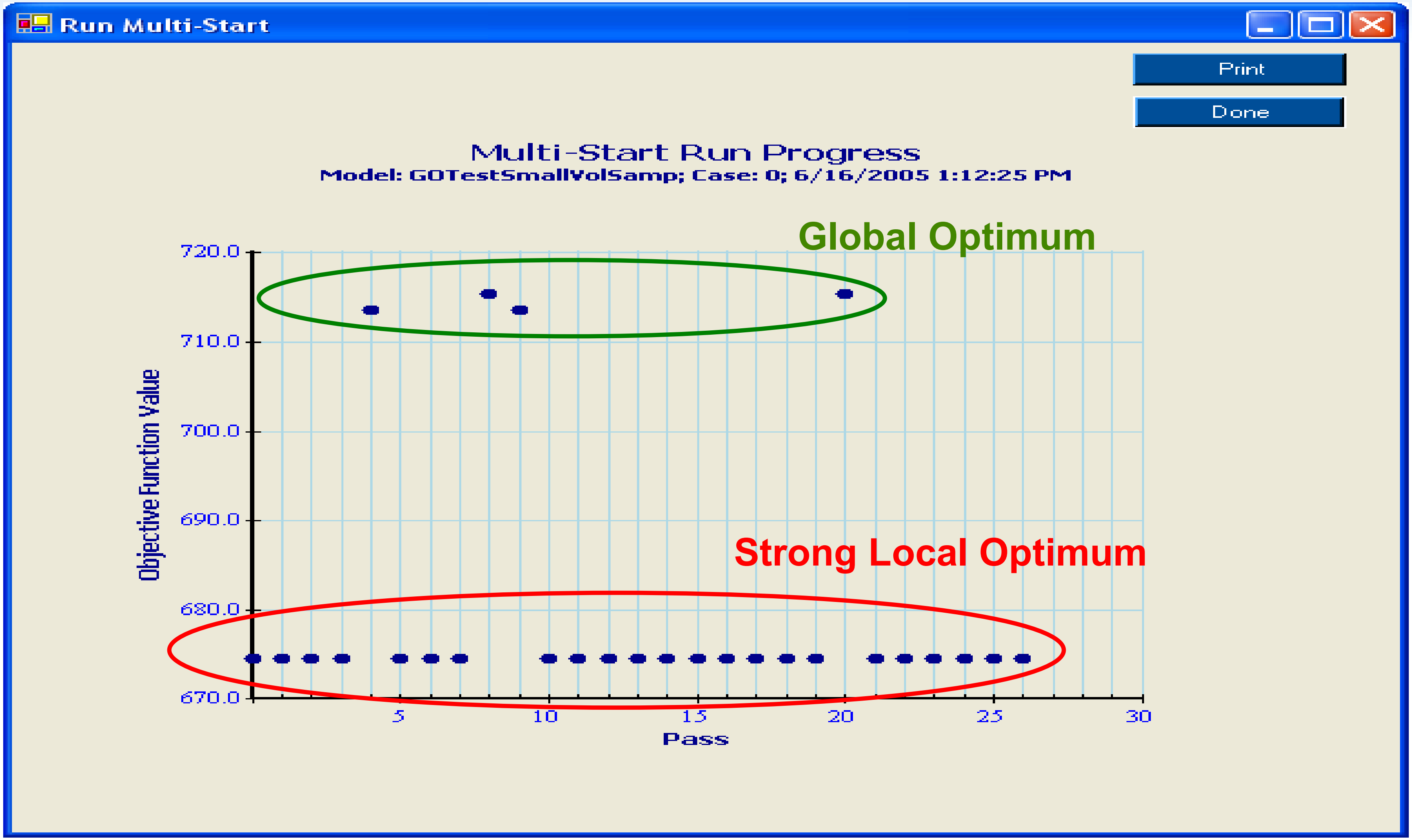
Goal Programming

- Ordered multi-objective optimization
- User defined secondary and tertiary objectives
- User defined relaxations
- Final economic optimization restores Lagrange multipliers

Global Optimization

- Three component strategy
- Powerful specialized algorithm incorporated into the PIMS Non-Linear Programming (XNLP) technology to avoid local optima often caused by inactive pools
- A highly efficient, parallel-processing, statistical multi-start algorithm consistently determines the globally optimal solution
- For certain classes of model non-linearity, a convex relaxation algorithm is able to prove global optimality of the solution found

Stochastic Global Optimization



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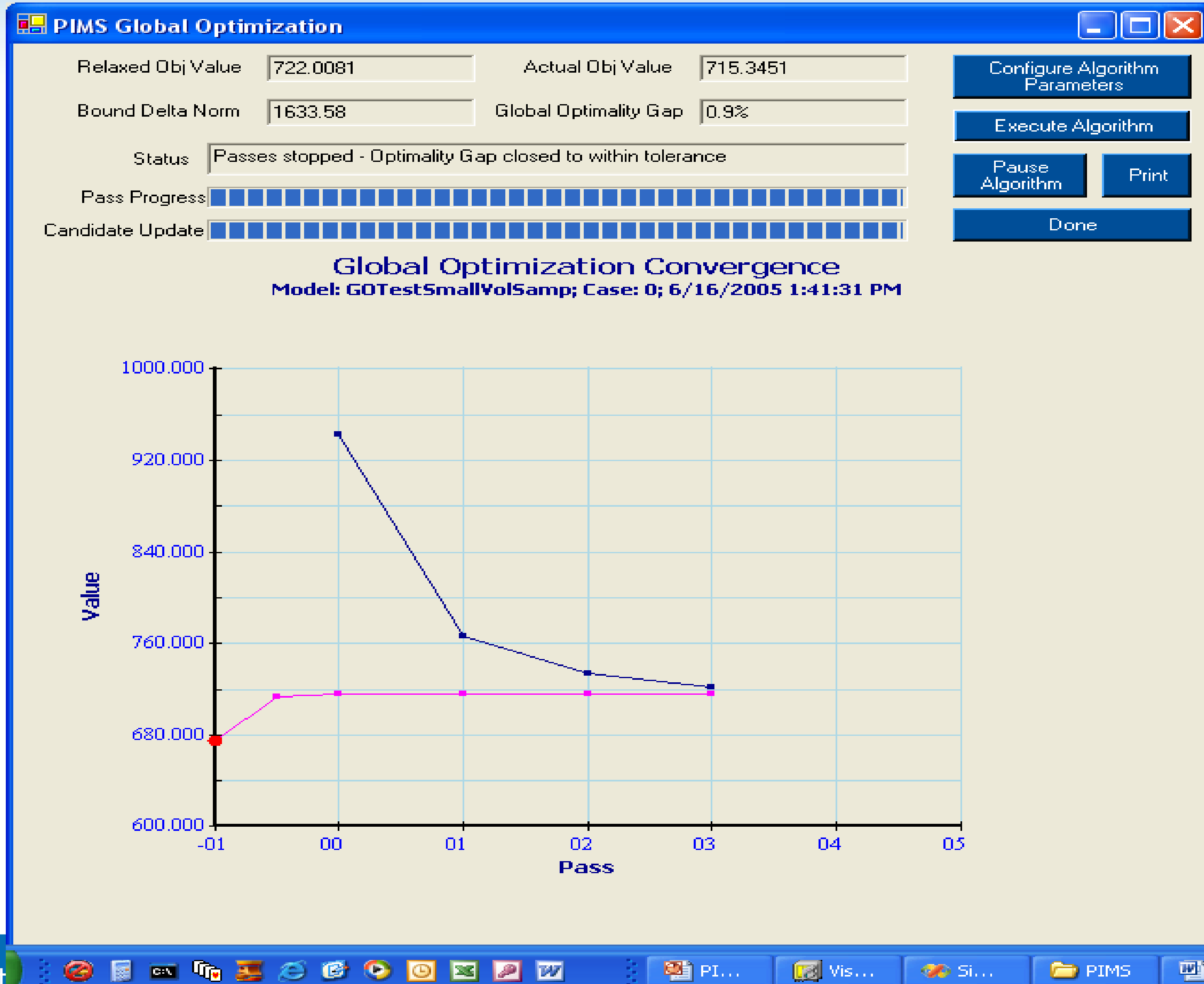
Convex Relaxation Framework

- Convexification of bi-linear and tri-linear terms
- Additional linear constraints are generated by applying a Reformulation-Linearization-Technique (RLT) technique to selected constraints of the original pooling problem
- Selective de-activation of RLT constraints
- Bound reduction algorithm

Deterministic Global Optimization



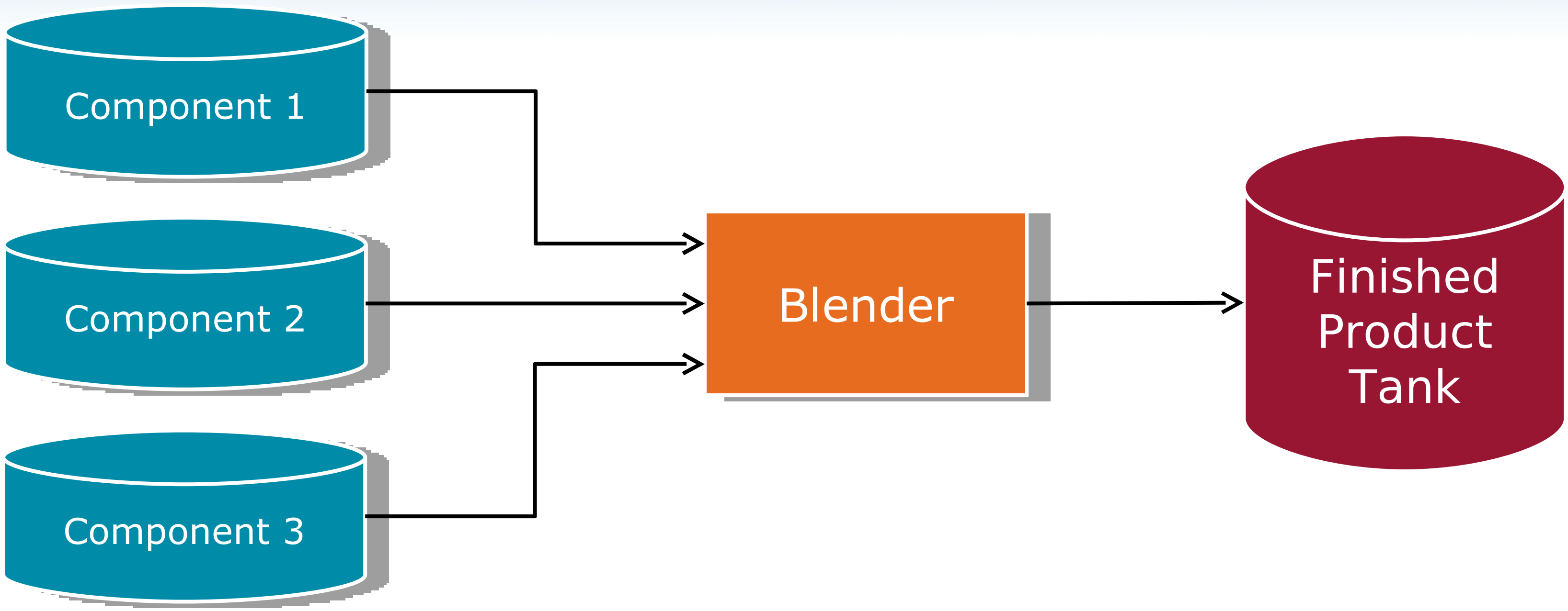
Key Points and Conclusions

- Created a powerful framework for supporting and augmenting the refinery planning optimization process
- Solution analysis for both feed stocks and products greatly enhances the current processes of crude trading and acquisition
- Global optimization framework using a combination of stochastic and deterministic techniques ensures best solution even for large-size complex problems

Introduction to Blending Operations

- The goal of product blending operations in a refinery is to
  - Meet all the shipments on schedule and on specification
  - Operate within the tank inventory constraints
  - Perform optimally in terms of overall cost and profitability
- Aspen MBO is an event based, multi-period, blending optimization system
  - Rich nonlinear blending property prediction correlations
  - State-of-the-art optimization
  - All major oil companies use it as well as many others
- The proprietary mathematical model optimizes
  - Blend recipe
  - Blend volume
  - Transfers
  - Shipments
  - Receipts

Standard (Inline) Blending

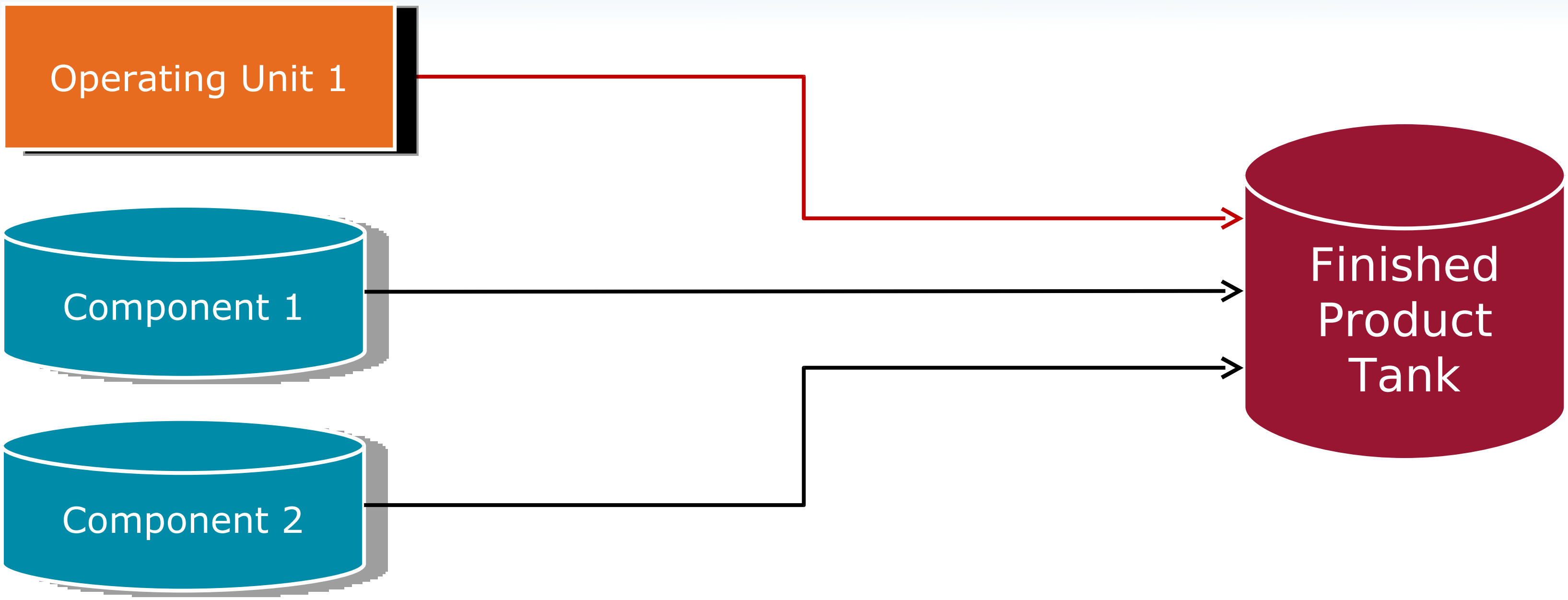


- Step 1: Schedule a blend
- Step 2: Components sent simultaneously through a header
- Step 3: Mix product tank and analyze results

Problem Definition

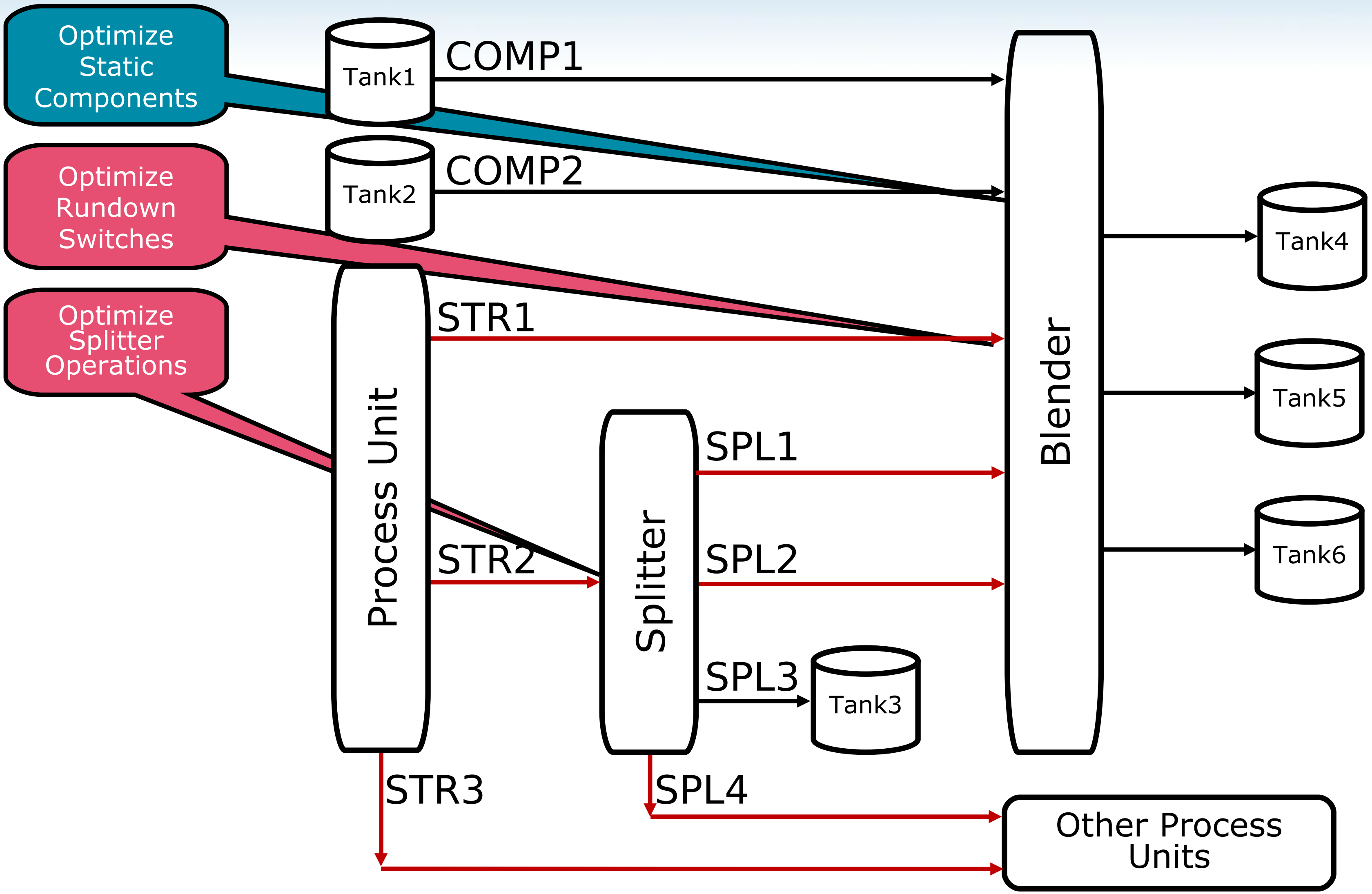
- Rundown blending describes a situation where at least one component comes directly from a process unit without an intermediate storage tank
- Problem definition
  - Traditional blending systems are not designed to optimize blending operations without tanks for all components
  - Most refiners in North America and Europe operate with sufficient intermediate storage
- Business case
  - Many refineries in APAC and Europe (eastern) have operations without component tanks
    - Most customers in those regions use excel with trial-and-error to get a feasible solution
  - Even in NA and Europe, diesel and fuel oil are blended without intermediate tanks
    - Recent strict sulfur regulations make blending a challenge

Rundown Blending

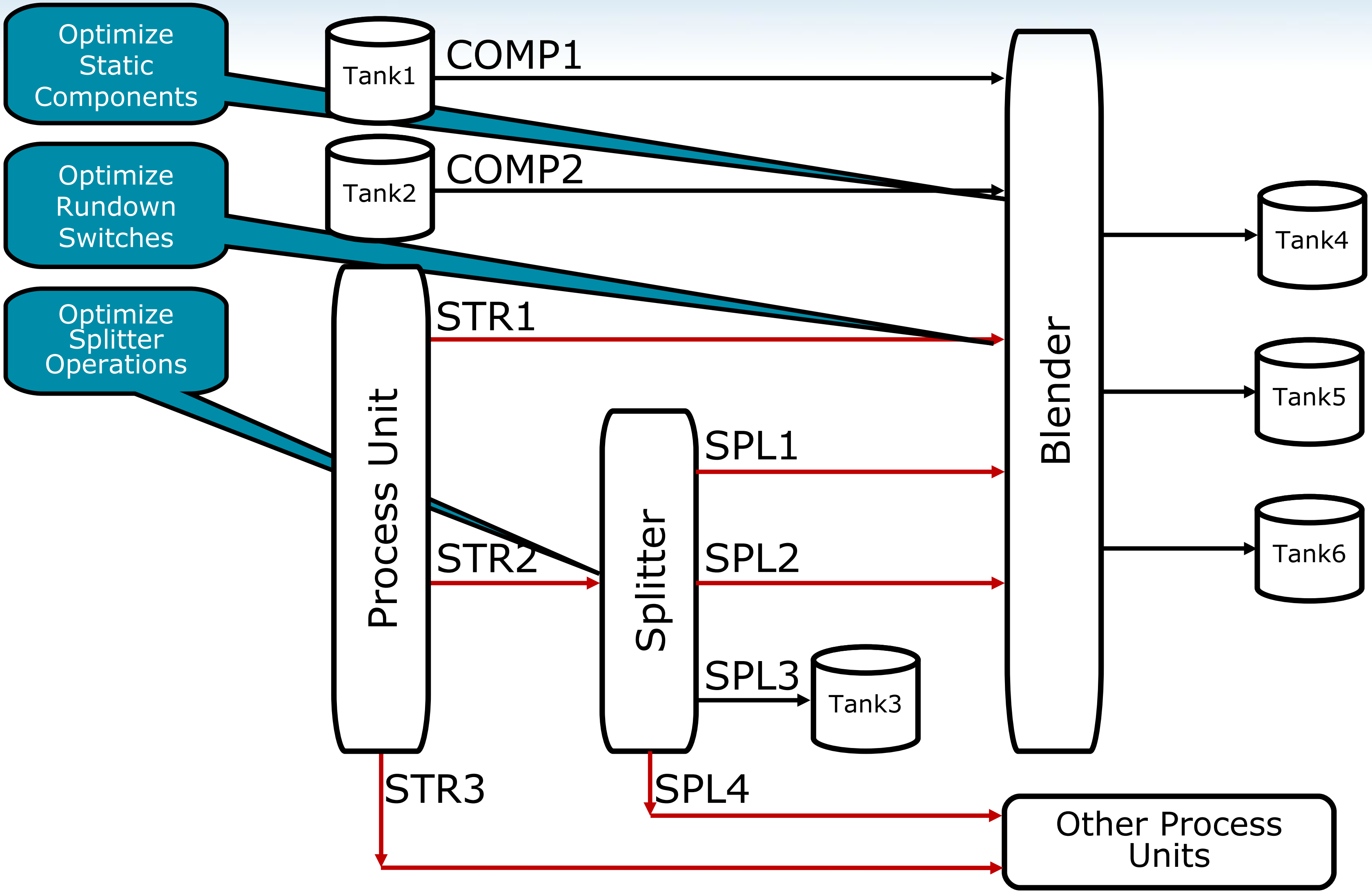


- Step 1: Schedule a blend
- Step 2: Operating unit lined up to product tank
  Static components fed simultaneously
- Step 3: Mix product tank and analyze results

Rundown Blending Optimization Scope



Rundown Blending Scope

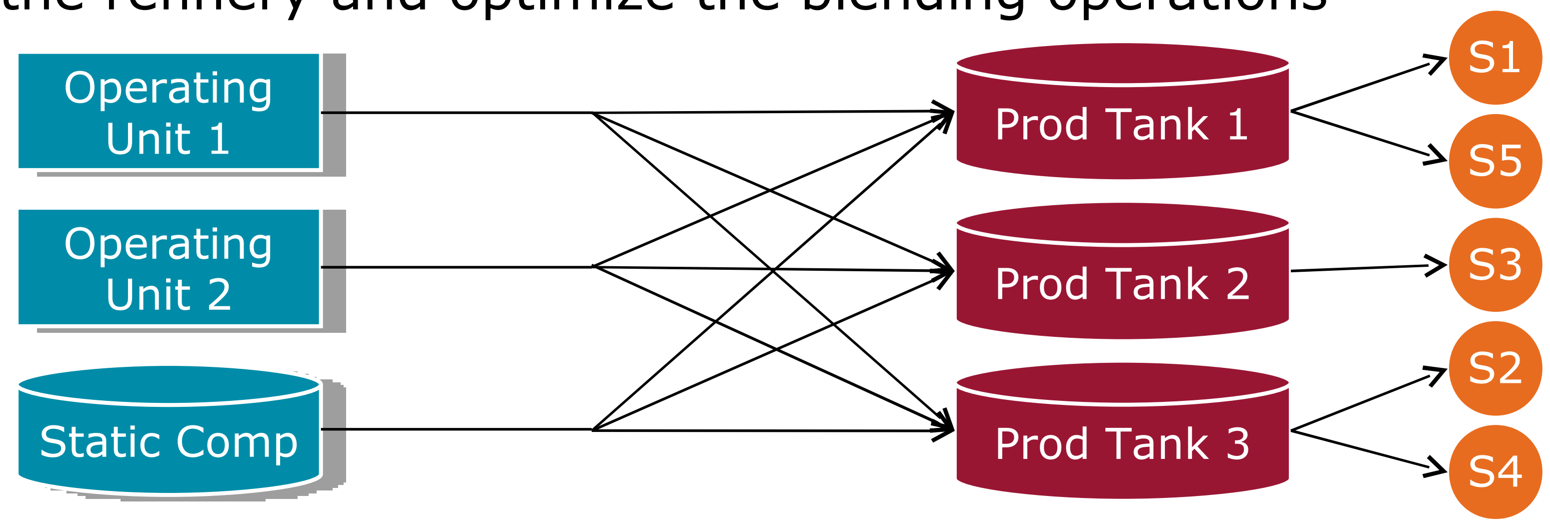


Model Structure

- Key features of the new model
  - Mixed-integer nonlinear programming problem (MINLP)
  - Global event-based continuous-time formulation
  - Solution of the model determines
    - Optimal recipe (static and rundown components)
    - Precise start and stop date and time
    - Rundown component sequencing for each period
    - Split ratio for components with multiple dispositions
- New formulation explicitly accounts for blend event sequencing and start and stop times using binary variables
  - Underlying problem is very large, nonlinear, and involves many discrete decisions
  - Provisional patent granted
- Framework for future expansion to optimal refinery scheduling

Example 1 - Hawaiian Refinery

- Actual customer blending operation for diesel blending
  - Horizon of 16 days
  - 6 blends created for low sulfur diesel
  - 2 rundown components and a static component
  - 3 product tanks
  - 5 fixed shipments
- Use Aspen Refinery Multi-Blend Optimizer (MBO) to model the refinery and optimize the blending operations



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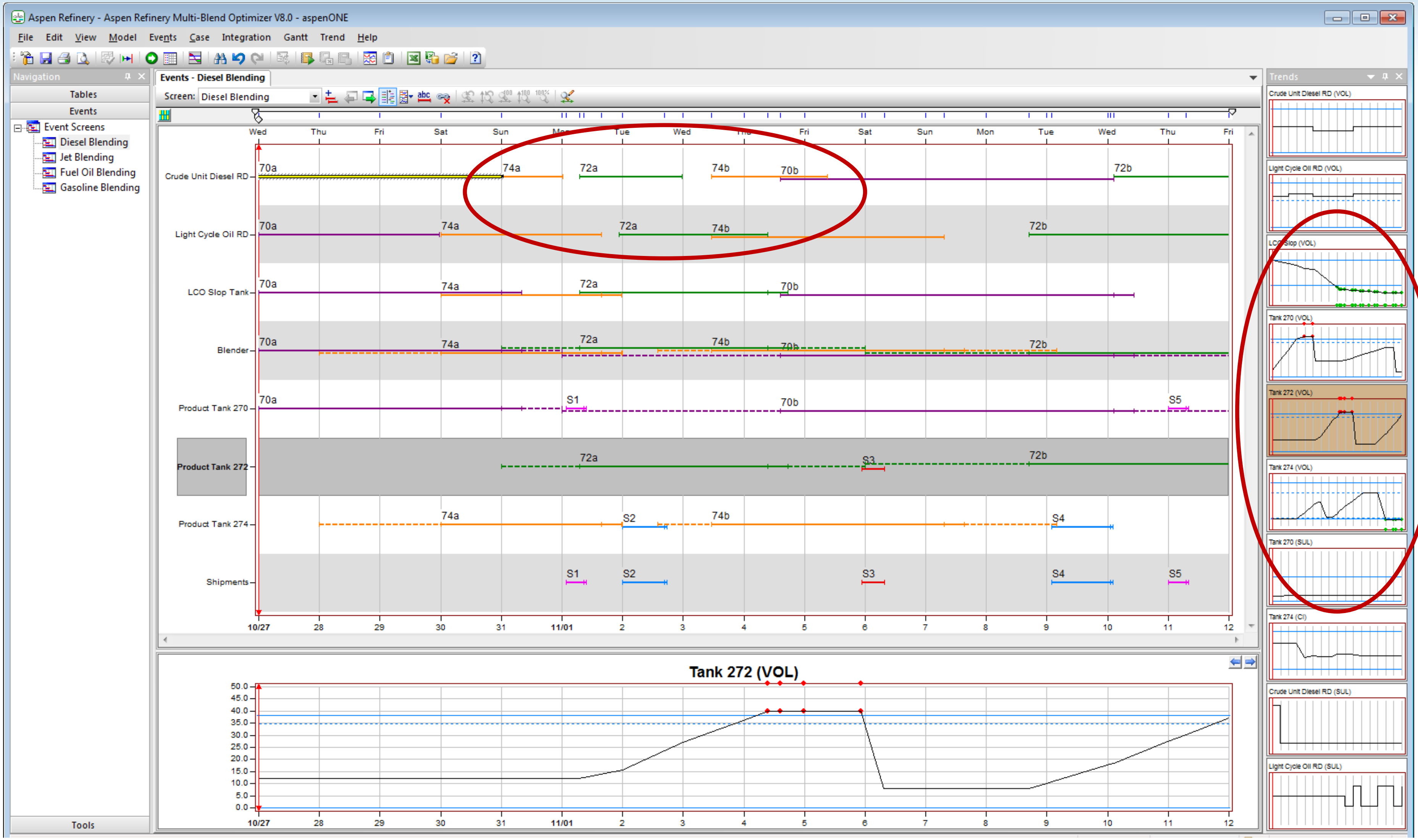
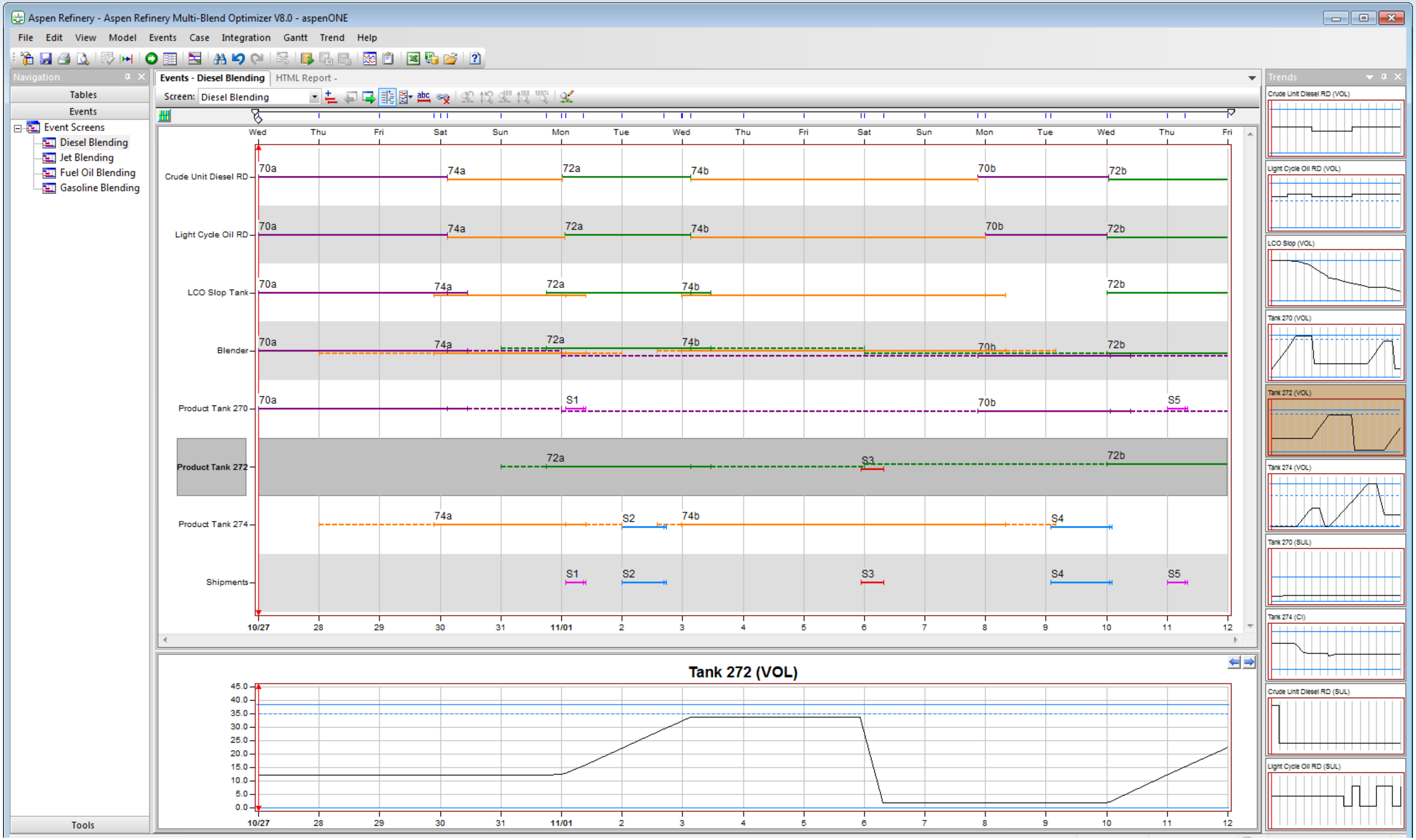
Example 1 - Hawaiian Refinery Initial

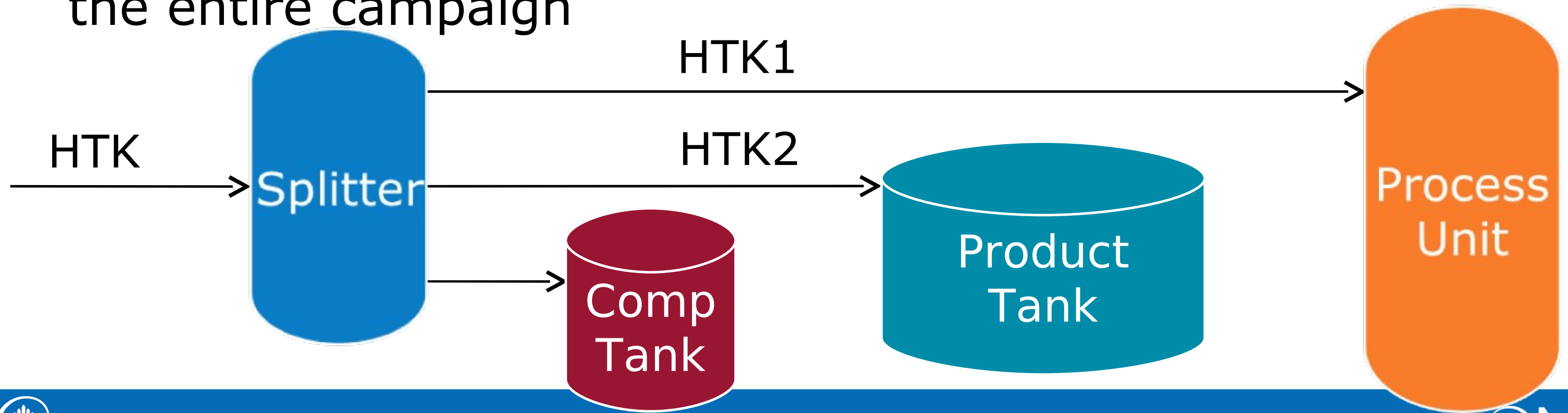


Example 1 - Hawaiian Refinery Optimal

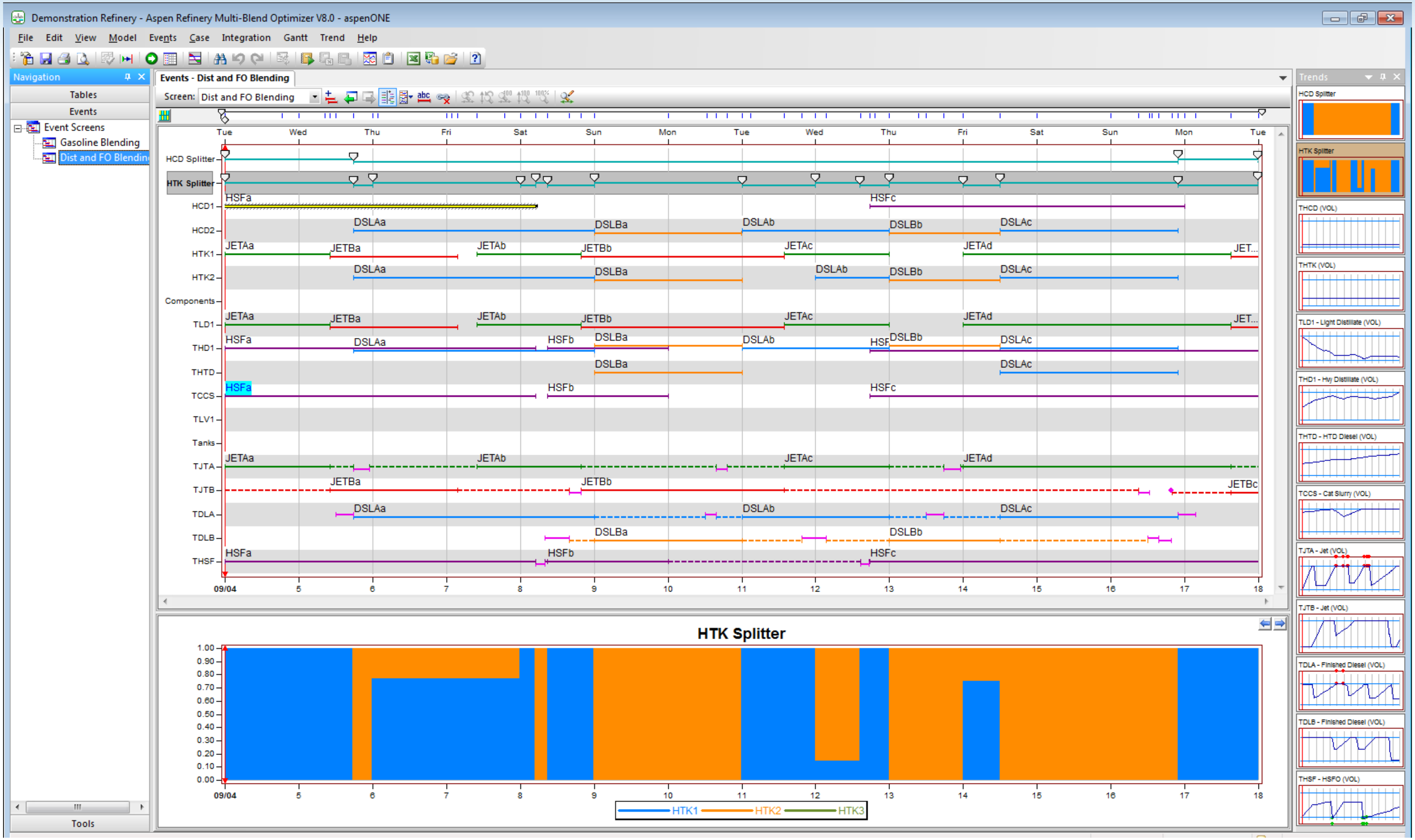


Example 2 - Gulf Coast Refinery

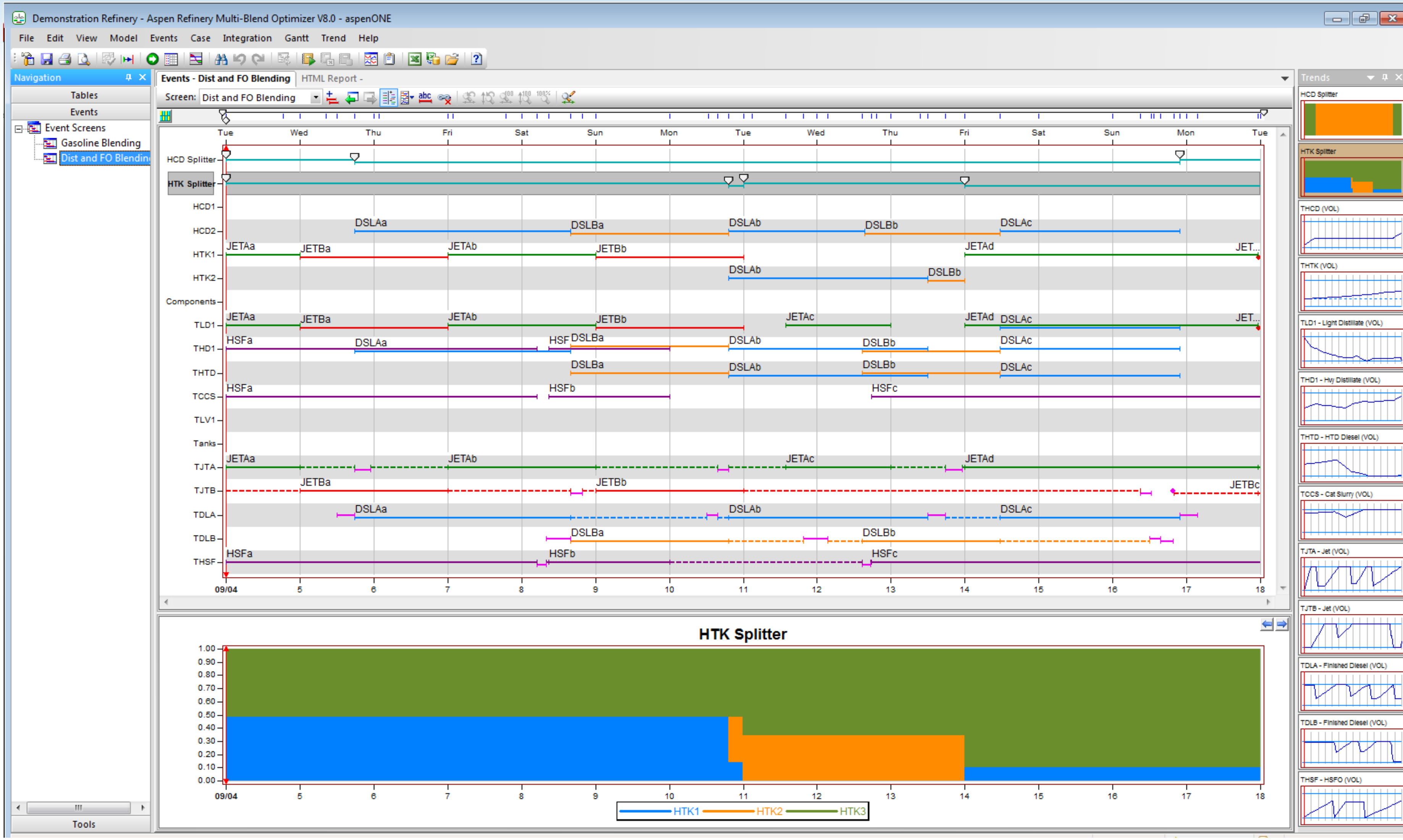
- The new model has also extended the mathematical formulation to handle splitting of the rundown streams to have multiple destinations
- For this example, we have 2 rundown streams split into 3 streams each, where only 1 of those 3 streams has storage
  - 4 total rundown streams used in blending
  - Time horizon is 14 days
  - 15 blend events for 3 products with 16 shipments
- Formulation minimizes the changes in the split ratio over the entire campaign



Example 2 – Gulf Coast Refinery Initial



Example 2 – Gulf Coast Refinery Optimal



Key Points and Conclusions

- The new formulation provides an optimal solution to complex rundown refinery scenarios - a challenging operational problem
- The mathematical model is automatically and dynamically constructed
- The approach has been validated on several commercial problems
- The proposed solution
  - Provides for stream containment
  - Ensures that all products meet their specifications
  - Minimizes the use of slop tanks
  - Minimizes operational upsets
  - Minimizes the incidence of product giveaway
  - Maximizes the refinery operating margin

Conclusions and Discussion

- Refinery operations have a long tradition of using state-of-art optimization
- Refining optimization has come a long way but there are remaining challenges
- Deterministic global optimization
- Large-scale optimization under uncertainty
- Schedule optimization
- Refinery-wide real-time optimization