Operations Research at Air Liquide

Presentation at ROADEF 2018: OR Practice
Lorient 23 February 2018
Outline

Introduction to Air Liquide and our Optimization activities

Real Time optimization Problem (Production)

Bulk Distribution Optimization project
  ○ Supply Chain Design Optimization Suite
  ○ Inventory Routing Problem

Conclusions

Useful Anecdotes
Introduction to Air Liquide and our Optimization activities
2016 key figures
(Following the acquisition of Airgas on May 23rd, 2016)

~65,000
EMPLOYEES (1)

Present in
80 COUNTRIES

Revenue
€ 18.1 BILLIONS (2)

Net profit
€ 1.844 BILLIONS

More than
3 MILLION CUSTOMERS & PATIENTS

(1) As of December 31st, 2016.
(2) Excluding Welding and Diving, restated as discontinued operations.
Major trends are shaping our markets

- ENERGY AND ENVIRONMENTAL TRANSITION
- CHANGES IN HEALTHCARE
- DIGITIZATION
Operations Research applications @ Air Liquide

> Supply Chain(s) Optimization(s)@Air Liquide

- Real Time Production Optimizer/Gas & Liquid Production planning
- Inventory Routing Problem [www.challenge.roadef.org](http://www.challenge.roadef.org)
- Tactical sourcing and asset management
- Cylinder Supply chain Dispatching
Pipelines ... and their optimization

For Real Time Optimization (RTO), R&D introduced which our production operations now use as a common optimization platform worldwide

Internal Advanced Process Control (APC) and Optimization conferences held every 2-3 years
Measuring Energy & Environmental Impacts
Significant Scale ... and opportunities for Operations Research & Analytics

<table>
<thead>
<tr>
<th>Energy and efficiency indicators for the Group as a whole</th>
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<tr>
<td><strong>Annual electricity consumption (in GWh)</strong></td>
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<tr>
<td>2012</td>
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<tr>
<td>27,578</td>
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<td>Annual thermal energy consumption (in LHV terajoules)</td>
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<tr>
<td>2012</td>
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<tr>
<td>229,177</td>
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<tr>
<td>Evolution of energy consumption per m³ of air gas produced</td>
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<tr>
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<tr>
<td>98.8</td>
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<tr>
<td>Evolution of energy consumption per m³ of hydrogen produced</td>
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<tr>
<td>98.4</td>
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● **Significant Scope:** In 2014, AL* consumed **30,341 GWh** of electricity, mostly in our air separation units (ASUs)
● **In Perspective:** In 2014, the US Energy Information Agency (EIA) reported **worldwide electricity production was 22,657 TWh**

(*AL = Air Liquide)  
Measuring Energy & Environmental Impacts

Significant Scale … and opportunities for Operations Research & Analytics


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<tr>
<td>Kilometers traveled by all vehicles delivering gas in liquid or cylinder form (in millions of km)</td>
<td>428</td>
<td>420</td>
<td>428</td>
<td>426</td>
<td>540* (1)</td>
</tr>
<tr>
<td>Estimate of CO₂ emissions generated by these vehicles in the Industrial Merchant activity (in thousands of tons)</td>
<td>471</td>
<td>462</td>
<td>471</td>
<td>468</td>
<td>600* (1)</td>
</tr>
<tr>
<td>Evolution of the distance traveled per ton of liquid industrial gas delivered (oxygen, nitrogen, argon, carbon dioxide) (1) (truck delivery)</td>
<td>97.8</td>
<td>95.3</td>
<td>94.8</td>
<td>92.2</td>
<td>90.3* (1)</td>
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Clear Key Performance Indicators & Metrics

- **Significant Scope:** In 2016, AL* trucks traveled 540 million km to deliver cylinders & bulk liquid to customers worldwide**
- **Continued Efficiency Improvements:** In 2016: km per ton delivered reduced by 2% versus 2015 (and 9.7% versus 2007)
Real Time Production optimization
Hierarchical Pyramid: Process Control & Optimization (Production)

Level 4
Planning & Scheduling (global basis)

Level 3
Plant Optim.

Level 2b
Advanced Process Control

Level 2a
Regulatory Control Loops

Level 1
Sensors / Actuators Equipment

Real Time Optimization (RTO) [hr]

Model Predictive Control (MPC) [min]

PID Control [sec]

Connection to Enterprise Resource Planning (ERP) System
Real Time Optimization (RTO)

### Problem to solve
Implement best setpoints and ramp the plant

### Energy price

### Actual process and pipeline values

### Target and schedule setup

### Customer demand

### Predefined

### Real Time Information

### Process Model

### RealTime Optimization

### Optimal setpoints

Li, et al. (2011)
SIO Optim Digital Twin Concepts

The Core Engine is...

- Mathematical model generator using a modular approach for Air Separation Units
- Is developed on AIMMS, the group preferred optimization platform
- Users configure applications that rely on the same mathematical model

- RTO
- Data Reconciliation
- Energy Nomination
- Liquid Scheduling
- Maintenance planning
- Budget

V1

V2
Bulk Distribution Optimization project

Supply Chain Design Optimization Suite,

Inventory Routing Problem
Transition to Vendor Managed Inventory (VMI)
Bulk (Liquefied) Gases delivered to customers via tractor-trailer

From **Customer-Managed Inventory (CMI)**
- Customer is responsible for monitoring & managing inventory
- Customer “calls-in” orders to AL
- Key decisions imposed on AL:
  - When to deliver?
  - How much to deliver?

To **Vendor-Managed Inventory (VMI)**
- AL is responsible for monitoring & managing inventory *(a service)*
- AL makes a full set of coordinated decisions
  - Flexibility
  - Efficiency
  - Robustness

Requires **Evolution**
- Convince customer to change to a VMI relationship
- Remote Telemetry
- Customer Demand Forecasting
- Inventory Routing Optimization

Requires Evolution
Hierarchical Pyramid: Distribution Optimization

- **Level 4**: Global Planning & Scheduling (production/distribution)
- **Level 3b**: Optimization (Assets)
- **Level 3a**: Optimization (Dispatch Decisions)
- **Level 2**: Forecasting
- **Level 1c**: Supervision
- **Level 1b**: Remote Telemetry Units
- **Level 1a**: Sensors

Connection to Enterprise Resource Planning (ERP) System

3b: Supply Chain Design

3a: Distribution Routing (Operations)
From Supply Chain Design to Operation
Bulk (Liquid) Distribution in a Vendor-Managed Inventory (VMI) context

Optimization Sequence

- **Strategic**
  - Sourcing
  - Tank Allocation
    - assigning customers to product sources
    - sizing storage at customer sites for efficiency (and robustness)
- **Operational**
  - Fleet Sizing
    - tractors, trailers, and drivers
  - Inventory Routing
    - daily deliveries and exact routes

AL sponsored the 2016 ROADEF/EURO Challenge, providing realistic test cases among others.

Users Worldwide:
- Argentina
- Germany
- Brazil
- China
- France
- Japan
- China
- Mexico
- South Africa
- Spain
- Turkey
- USA
Overview of Supply Chain Design Optimization suite

Since 2009, AL has developed a suite of **decision support tools** for **optimization** of the **bulk supply chain design efficiency**.

**Tank Allocation module** answers: Which customers are opportunities for a **tank change** – and what **savings in distribution costs** should I estimate?

**Sourcing module** answers: How should I **allocate customer demand among various sources**?

**Fleet Sizing module** answers: What **vehicles & drivers** do I **allocate** to each **depot** for each period?

Developed by AL (R&D, Advanced IT, & World Business Line) in collaboration* with Virginia Tech and CELDi. Applying R&D expertise in **Operations Research & Software Development**.
Tank Allocation: Problem Overview

Optimizes **Net Present Value (NPV)** of Tank Change Investments & Distribution Costs

Simulates **Distribution Cost / Routing** to meet customer demands

Recommends **New Tank Allocation** including Refurbishment & Purchasing decisions

1. Loading cost at source
2. Unloading cost at customer
3. Distance cost for road delivery

**Distribution Cost**

1. Purchase cost
2. Refurbishment cost
3. Tank Removal cost
4. Tank Installation cost
5. Warehouse transportation cost

**Investment**
Method: assume constant demand

- **Academic Research to Address Clear Challenges**
- **Phase 1:** Cluster Customers and Generate Candidate Shifts
  - Sweep Algorithm
- **Phase 2:** Select Shifts and Allocate Tanks
  - Mixed Integer Linear Program (MILP)
Sustained Collaboration (2009-15)

- **Evolution of Collaboration with Virginia Tech**
  - **From:** delivering the full solver
  - **To:** developing new methodologies
  - Students: PhD, MS, undergraduates

- **Flexibility & Transparency**
  - Changes in Scope necessary
  - More Time / Budget required as challenges arise

- **Project Timeline**
  - v1.0 proof-of-concept
  - v1.2 deployed, **delivering value** (constant customer demand)
  - v2.0 development (model relaxation, time-varying demand)
  - v2.0 deployed as a **success**, project closed
Overview of Bulk Inventory Routing Optimization

The **goal** is to optimize the bulk distribution / transportation planning over the long term

- Minimizing the **logistic costs**
- Providing a **high level of product availability** for our customers
  - Avoid product shortage (run-out) at the customer tank
  - Satisfaction of orders of call-in customers

- Collaborations with: Innovation24 : 2008-2013
- Paris 13 University : 2013-14 Post doc on exact methods

Applying R&D expertise in **Operations Research & Software Development**

AL sponsored the 2016 ROADEF/EURO Challenge, providing realistic test cases
Conclusion & Useful Anecdotes
Keys to Success in Academic Collaborations

**WIN WIN**

- All are fortunate to collaborate
- Delivers Value for all
  - $ / € for industry
  - publications/thesis for university researchers
- Good Relationship = Good Influence

- Challenging, **Valuable**, Pre-competitive Project
- Flexibility & Transparency of Academic Partner
- Exploratory Focus over the Longer-Term
Manage Reasonable Expectations

- **Outline a clear path to achieve vision**
  - Identify potential successes *(victories)* along the way
- **Don’t let the perfect be the enemy of the good**
  - 1st goal: Perform better than before
  - First Do Better, eventually Do Best (if possible)
- **Set reasonable expectations**
  - What appears simple and straightforward often is not so
  - Make sure stakeholders *appreciate* the level of the challenge
  - If end-user can do better / improve upon solution, train them to expect this and encourage them to try
Interacting with Stakeholders

- **Proactively Identify and Involve Potential Stakeholders**
  - **Management** [business value, $/€, resources]
  - **Subject Matter Experts** [problem definition, validation]
  - **Operations** [end-user of tool or its results]

- **Genuinely Solicit Stakeholder Feedback & Respond with Empathy**
  - If you **solicit** feedback, you should be genuine and **consider it**
  - Respond with necessary detail, including rationale
  - Respond with empathy, understand stakeholder’s perspective

- **Identify & Address Underlying Question, Concern, Request or Need**
Maintain Reliable Data

- Reliability of Data → Reliability of Tool
  - Requires clear **responsibility** and **accountability**
- **Industrial IT platform technology alone is insufficient**
- Particularly true for “open-loop” decision support tools
  - Regular, specific **end-user action required** to implement solution
  - Early stage: rely on end-user to collect data
  - Increased reliance on ERP (vs. pre-existing manual methods)
  - Generally infeasible for end-user to take responsibility for all data
Overcoming Skepticism and Resistance
Inspired by UPS TED talk by Jack Levis

“All truth passes through three stages …
● First, it is ridiculed
● Second, it is violently opposed
● Third, it is accepted as being self-evident”

Arthur Schopenhauer

“Essentially, all models are wrong, but some are useful”

George E. P. Box

Sometimes, resistance comes in the form of requests for more
For further information

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