Using an Ant System and a Genetic Algorithm To Schedule Production and Delivery of Liquid Oxygen and Liquid Nitrogen To 10,000 Client Sites

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Outline

- About the problem
- About the solution
- Future work
- System demo

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About The Problem

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Air Liquide

- North American operations based in Houston
- Produces liquid oxygen and nitrogen at 20+ plants
- Delivers by truck to 10,000+ client sites
- Sites get deliveries once per week on average
- Production and distribution are run from an Operation Control Center in Houston
- The bulk of the cost is from electricity to produce the products
- Air Liquide would like to minimize production and distribution costs while satisfying all business constraints

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Problem Constraints

- Energy costs vary by location, by provider, by season, and by time of day, and are forecast
- Client demand is forecast for the week ahead
- Deliveries can be made to client tanks after they reach a trigger level
- Deliveries must be made to client tanks before they reach a safety level
- Some clients have time windows on deliveries
- There are OSHA constraints on driver time
- Number of trucks is limited in the short-term

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When Can You Deliver?

Client Tank

Trigger level—can deliver

Safety level—must deliver

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About Cost

- Production costs aren't linear by level of plant or number of hours per day that the plants are run
- Energy costs go up or down based on the weather and other predictable (!) conditions
- Energy "spikes" are possible—rising from $66 per kilowatt hour to $999 in a few hours, lasting for a few days
- Transportation costs are by driver time and distance

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More Features of the Problem

- If you deliver to one remote client, it may be good to deliver to others in the same region
- Bulk transfers of product can be made from one plant to another at a lower rate than regular transport costs
- Plant shutdowns can save money, but you incur startup costs when the plant is restarted
- The split between oxygen and nitrogen at a plant is variable, with limits

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About The Solution

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Scheduling Production

- The system uses a genetic algorithm to schedule production for each plant
  - Specifies production level (from 70% to 100%)
  - Schedules shutdowns
  - Schedules splits (oxygen versus nitrogen within limits)
  - Schedules bulk transfers of product to other plants

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Scheduling Distribution

- Distribution uses an ant colony originally implemented by Bios Group to do the distribution
  - Decides what days to deliver product to what client sites from what plants
  - Decides what to do with excess product from a delivery
  - Computes cost of delivery based on its schedule
  - Can require 20,000 iterations (20 minutes) to generate a good distribution schedule
  - Learning modifies a set of weight vectors (pheromones)

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Integrating the Ant Colony and GA

- The ant colony depends on the GA to compute how much product is available at which plants
- First plan: use the GA to generate a production, and then use the ant system to distribute it. Then evaluate the result. That's the GA solution evaluation
  - Problem: each GA solution takes 20 minutes to evaluate, but the system has to run to completion in under six hours

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Integrating the Ant Colony and GA

- Final plan: use the GA to generate a production schedule
  - Use n iterations of the ant system to distribute the product
  - The best solution gives the evaluation of both the ant system and the GA solution
  - Update ant system pheromones infrequently
  - The ant system pheromones and the GA population act together to *** CO-EVOLVE ***

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The Co-Evolutionary Flow

1. Generate a GA production solution
2. Evaluate it with n ant solutions and remember the best
3. If the number of ant solutions is greater than the ant update interval, update ant pheromone vectors
4. Carry out the usual GA population management (steady-state, ranked, linearly descending evaluations)
5. If we've evaluated enough GA solutions, return the best solution. Otherwise, go to 1.

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Current Status

- System is working to impact Air Liquide operations
- Potential for dollar savings is great
- Some resistance from the distribution side of the business
  - Their bonuses are based on minimizing distribution costs
  - Bulk transfers and shipment from a farther (but cheaper) plant impact their bonuses
  - Bulk transfers and shipment from a farther (but cheaper) plant save Air Liquide money

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Future Work

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Always More Features to Add

- Hourly scheduling rather than daily
- Global targets for production
- Shipment to client tanks in anticipation of energy price spikes
- Better distance/time calculations for routes
- Temperature-sensitive production costs
- Integration with pipeline production system

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System Demo

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