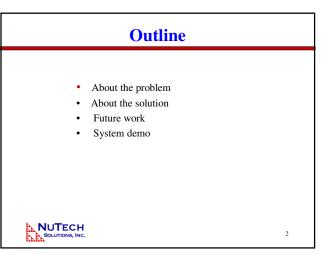
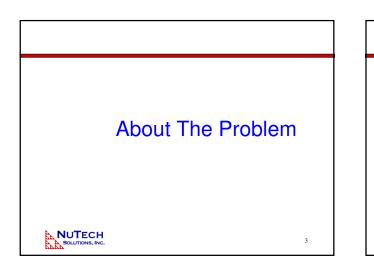


David Davis VP of Product Research NuTech Solutions, Inc.

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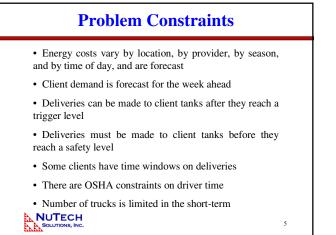
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Air Liquide

- 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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Client Tank Trigger level—can deliver Safety level—must deliver

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





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 NUTECH 12 SOLU

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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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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