Agent-Based Simulation for Logistics and Plant Management

Nutech Solutions and Air Liquide America
A Case Study

1. Introduction

This document presents a case study examining the work of NuTech Solutions, a software development company that focuses on solving difficult logistic business problems using a wide range of cutting edge techniques. In particular, we consider the system developed for the energy transformation company, Air Liquide America. Delivering a hybrid system combining both agent-based technology with evolutionary computing techniques, NuTech Solutions provided a state of the art optimisation and production scheduler that helped Air Liquide America maintain their position as the market leader in the highly competitive energy transformation market.

The document is structured as follows. In Section 2, we present an overview of Air Liquide America and the challenges facing the company, while in Section 3 we provide a profile of NuTech Solutions and their main product range. Then, in the main body of the case study in Section 4, we describe the collaboration between Air Liquide America and NuTech Solutions, the technologies used to meet the challenges facing Air Liquide America, and the final product. Finally, Section 5 presents some reflections on a collaboration such as this, and the specific areas in which Nutech believes agent-based technologies can have an impact.

2 Air Liquide America

Founded in 1902, the Air Liquide Group is the world leader in the production, distribution and transformation of industrial and medical gases [2]. Their global presence (130 subsidiar-

ies in more than 65 countries) allows them to combine the resources and expertise of a global enterprise with a powerful local presence based on independent customer-focused teams. Sales in 2003 totalled 8,394 million euros, with gases and services accounting for 7,388 million. The group is listed on the Paris Stock Exchange, is a member of Eurostoxx 50 and has 31,900 employees worldwide as of December 2003.

Air Liquide America [1], the U.S. division of the Air Liquide Group, currently serves more than 8,000 customers nationwide, from more than 75 sources, and with more than 400 transportation units.

2.1 The Core Problem

Recent years have seen substantial change in the energy transformation market caused by deregulation, fluctuating energy prices, changes in customer demand and changes in production and delivery costs. With a commitment to maintain their position as market leader, Air Liquide America sought to develop a system that would enable them to meet the growing challenges facing the industry.

At the heart of the challenges facing Air Liquide America was a need for real time evaluation of their supply chain assets. This required methods for responsively constructing production schedules across many different products and plants. Such schedules must be responsive to a large number of dynamic constraints and thus be modifiable on the fly. Related to this was the problem of finding optimal product routing policies from Air Liquide America's plants to its customer sites. Again, these policies had to be responsive to variations in customer demand and the changing constraints placed on the production plants. These two core challenges drove the development of a system that would allow them to efficiently schedule the production and distribution of products from more than 40 plants to 10,000 customer sites. In summary, the proposed system had to enable Air Liquide America to:

- value and optimise their assets and supply chain;
- reduce production and distribution costs;

- deploy systems to capture lows in energy pricing;
- produce and store products in their own plants;
- deliver products cost effectively, where and when customer demands;
- project energy prices, customer demand, and inventory levels; and
- make optimal risk decisions that have significant impact on profits.

As a consequence of meeting the above objectives, Air Liquide America expected to make annual gains of $20 million, resulting from new market opportunities and operational savings. It was within this context that Air Liquide America approached NuTech Solutions and commissioned the system that would meet these upcoming challenges.

3 NuTech Solutions and Intelligent Business Engines™

Founded in 1999, NuTech Solutions [3] has a mission to develop dynamic technology solutions able to intelligently learn and adapt. The company has 6 offices in 3 countries, and has helped over 50 corporate and government clients solve a range of problems. NuTech Solutions' activity spans a wide range of sectors including the automotive industry, consumer products, financial services, communications, manufacturing and energy, and has provided advanced predictive analysis and profit optimisation software products for many Global 1000 companies. The company portfolio expanded to cover solutions and applications based on complexity science with the acquisition in 2003 of BiosGroup, a world leader in the science of complexity and complex adaptive systems.

In this context, NuTech Solutions developed their core solution approach, the suite of Intelligent Business Engines™, which analyse, predict, optimise and adapt to solve challenging business problems while creating tangible business benefits. Intelligent Business Engines™ have been successfully applied to many areas, including:

- data preparation and mining;
- modelling;

- simulation and forecasting;
- optimisation; and
- prediction and forecasting

4 Solution Development

Having identified the challenges, Air Liquide America approached NuTech Solutions with a business case describing the core problem and their solution requirements. After a period of validating the business case, employees from both Air Liquide America and NuTech spent 15 months working on the initial development phase of the project, which required a great deal of interaction between the two companies (at times requiring virtual meetings with up to eight participants). Such intense interaction was necessary in order to facilitate the transfer of vital domain knowledge from Air Liquide to NuTech Solutions. In these early stages, between three and four NuTech employees were required, each of which brought important skill sets to the project, including:

- expertise in analysing optimisation problems;
- expertise in database management and integration; and
- expertise in GUI design to provide the front end systems for Air Liquide's staff.

4.1 Implementation Techniques

After considering a number of traditional operations research and mathematical programming solutions, NuTech Solutions determined that the nature of the problem required an innovative approach. The highly non-linear aspects of the problem meant that it was not amenable to traditional analytical modelling techniques and, thus, demanded the use of non-traditional methods. This led the NuTech team to consider adopting an approach based around simulation. However, the complexity of the problem meant that it was unlikely that any one solution approach would likely succeed alone. Based on these considerations, NuTech decided that the optimal approach was to construct a hybrid system utilising agent-based and evolutionary computation approaches. At the core of the system is an ant system optimisation approach that

has the task of discovering efficient distribution routes for Air Liquide's products from plant to customer. Coupled to this is a genetic algorithm that searches for highly optimal production level schedules for the individual plants. Underpinning these two techniques are a host of expert heuristics derived and modelled on the knowledge and expertise developed by Air Liquide. Combining all these techniques, NuTech Solutions developed a unique product, the Supply Chain Production Optimiser, which is able to respond and adapt to all the interfaces across Air Liquide's energy transformation business.

4.2 Ant System Optimisation

The agent-based modelling used by NuTech is an ant system optimisation technique, which exploits discoveries found in the study of real ant colonies and their self-organising capabilities. When foraging for food, ant colonies quickly converge upon the shortest possible paths to food. This is achieved by each individual ant laying down pheromones that other ants follow. As more ants travel down the same path the pheromone trace becomes stronger and thus attracts more ants, until only the shortest and most used paths remain.

Nutech models relevant components of Air Liquid's gas plants as ants; for example pipes and transport vehicles are represented as ants so that the overall plant can be modelled as an ant system searching for optimal routing policies.

4.3 Genetic Algorithms

Coupled to the ant system optimiser is a genetic algorithm (GA), which is a computational model of evolutionary processes that can perform highly parallel search across large, multi-dimensional search spaces. Specifically, GAs mimic the evolutionary processes of mating and mutation across a population of individuals, called a generation. By modelling aspects of the routing solutions given by the ant system optimiser as individuals of a population of solutions, the GA can then combine different solutions through simulated mating (in which aspects of two solutions are combined) and perform small mutations on each to generate new solutions that form the next generation. Within each generation, there can be many hundreds of solutions, each of which is then tested for fitness given some evaluation criterion; the best of these

can then be mated in turn to produce the next generation of solutions. This process continues over many generations until the most optimal routing policies are found.

4.4 The Supply Chain Production Optimiser

Exploiting the combined power of ant system optimisation and genetic algorithm search, the Supply Chain Production Optimiser takes into account the production schedules of all of Air Liquide's plants and adapts them to projected energy prices, weather changes, client demand and desired inventory levels. Utilising data representing 7-day power prices, customer demand projections, daily power costs and efficiency measures from every plant in the Air Liquide network, the system evaluates production costs based on forecast demand to determine which plants should produce which products. In addition, the system can model and consider potential plant production capability, maintenance and power issues that may impact on the generated schedules. All of this vital information can then be fed to the Air Liquide Operations Control Centre to enable adjustments to be made to the operation of the plants to meet production requirements across the whole network.

5 Reflections on Agent-based Solutions

In this section we briefly report some of the reflections that some members of the NuTech Solutions team have had regarding the process of providing agent-based solutions and the collaboration during the project.

5.1 Communication

In order for the collaboration between NuTech and Air Liquide to be effective, much learning on both sides had to take place. One of the main difficulties facing the project was eliciting the right kind of information from Air Liquide in a form that was computationally representable. Much of the initial developmental phase of the project was spent establishing and making explicit the wealth of background knowledge and assumptions that Air Liquide's staff brought to their day-to-day problems and challenges. Making sure that the NuTech engineers understood the language and terminology used by Air Liquide, and ensuring that errors in understanding

were caught and corrected became a key focus in the early stages of the project.

5.2 A Role for Agent Technology

Many of NuTech's successes with agent-based approaches arise in domains that require planning under uncertainty. In such domains, traditional planning approaches can result in plans that are brittle and prone to failure. Uncertain environments require robust plans that, while not always provably optimal, assure that the system will not fail in the face of environmental change. One way NuTech Solutions discovers these plans is through agent-based simulation, in which parts of the system are represented by agents. Once a simulation is constructed, candidate plans can be tested across a wide variety of simulated events, enabling the discovery of robust plans that guarantee a high degree of performance over varying circumstances. Using the multi-agent based ant system optimisation approach allowed NuTech to develop flexible routing strategies that allowed products to be transported efficiently through the network even when unexpected events occurred.

6 Summary

In this document we have described a collaboration between NuTech Solutions and Air Liquide America, who decided that the challenges facing the industry required a novel approach to their scheduling and routing problems. Drawing on their expertise in solving complex and difficult logistics problems for a wide variety of clients and industry sectors, NuTech Solutions determined that a hybrid approach, combining several cutting edge technologies was required to effectively tackle the problems facing Air Liquide. By combining a multi-agent ant system optimiser with a genetic algorithm and a suite of expert heuristics, NuTech was able to develop a system with enough responsiveness and creative problem-solving power to meet the requirements of Air Liquide's business case. Working through collaboration, both companies achieved what is recognised as one of the most successful applications of these techniques, and which has had an enormous impact on the way that Air Liquide conducts its operations.

References

[1] Air Liquide America. http://www.us.airliquide.com

[2] Air Liquide. http://www.airliquide.com

[3] Nutech Solutions. http://www.nutechsolutions.com

Steve Munroe, Roxana Belecheanu and Michael Luck
School of Electronics and Computer Science
University of Southampton
Southampton SO17 1BJ
United Kingdom
{sjm, rab2, mml}@ecs.soton.ac.uk

Bryan Woody
Nutech Solutions Inc
121 West Trade Street
Interstate Tower, Suite 1900
Charlotte, NC 28202
USA
bryan.woody@nutechsolutions.com

www.nutechsolutions.com
www.airliquide.com
www.us.airliquide.com