The Optimatics Letter

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Earthquake Planning with GA Optimization

Our discussions on GA with water utility staff at the CA-NV conference in San Diego often led to the question of how the Optimatics Genetic Algorithm (OGA) might be utilized to help California utilities and water districts plan for a major earthquake event.

Emergency planning actually is a great application for the OGA since the problem involves sorting through a large number of possible operating responses to identify the best options for a wide range of emergency conditions. If properly formulated, the OGA can identify more and better solution alternatives than would be possible using traditional trial-and-error simulation analysis.

Problem Statement

Being prepared for a potentially catastrophic earthquake is serious business in California as you can well imagine. Governments, businesses, and service providers including water utilities conduct contingency planning to determine how best to respond if certain events occur. In the planning process a water utility might ask:

- How can we continue to provide sufficient water to area A if transmission pipeline P (or facility Q) fails during an extreme event and cannot be repaired for X days or months?
- What level of service (quantities and pressures) can we reasonably provide during such an emergency?
- How do we respond to multiple breaks or outages?
- Do we need alternative plans if repairs take much longer?
- Are emergency connections to neighboring systems a cost-effective option?

OGA Formulation

Let's look at how we might formulate the Optimatics GA to answer these questions for a typical transmission and distribution system. First, the optimization problem is defined in terms of an objective function, a set of decision variables, and a set of constraints.

The **objective function** is a bit tricky for an emergency planning problem. We don't really care about costs, but nevertheless we choose as an objective to minimize the cost of system operations over the emergency period plus the cost of related capital improvements.

The costs being minimized are the operating and improvement costs <u>and</u> the penalty costs assigned by the OGA to any solution that fails to meet all of the design or performance constraints. Thus, the minimizing costs objective is really a surrogate for maximizing system performance.

Appropriate **decision variables** are next selected based on the specific operational decisions the water utility can make. The decision variables might include individual pump status and individual regulating valve settings for the specified demand conditions.

If the utility wants to consider construction of a new emergency connection to an adjacent water system or a new storage reservoir at any one of several sites, those capital improvement options are also included as decision choices.

Finally a set of **constraints** is defined. In order to be feasible, the OGA solutions need to satisfy all constraints for each specified demand case (see below). System

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***A helpful GA trick*:**

Use "minimizing cost" (including penalty costs) as a surrogate for "maximizing system performance"

Feedback from Interested Utility Staff

This past year we enjoyed exhibiting and presenting technical papers on GA pipe network optimization at national and regional conferences in New Orleans, Fort Worth, Chicago and San Diego. Our latest trip to the California-Nevada AWWA conference in October 1999 was particularly interesting since we were able to talk with many clients about the exciting optimization results being achieved on our Grand Prairie, Texas Water Master Plan study with CH2M Hill/Dallas (to be described in the next issue of *The Optimatics Letter*). The feature article in this issue addresses a topic of particular concern to California water utilities, namely earthquake planning.

performance requirements are set as constraints, such as minimum and maximum node pressures, maximum pipe velocities, and perhaps minimum storage level drawdowns to ensure reservoirs can be replenished and ensure adequate turnover to maintain water quality.

Demand Cases to be Analyzed

The specific demand cases for the earthquake planning problem are quite different from the typical simulation cases of maximum day, peak hour, maximum day plus fire flow, minimum hour (or maximum storage replenishment), and extended period simulation (EPS) demands.

The water utility may already have a number of emergency scenarios in mind to evaluate the "robustness" of its existing system. These scenarios are developed further by defining the specific performance criteria and projected duration for each case.

Let's say the utility comes up with 20 different emergency demand cases, some very simple and some more complex like the following:

1. The transmission main from one of its three water sources fails along with several other large distribution pipes in the area. Repairs will take 30 days. An operations plan is needed to keep pressures at 25 psi throughout the area without reducing the level of service too much in other areas of the system. An emergency connection to the utility's neighboring system to the east is available.
2. Same emergency condition as 1. above, but in this case the utility's neighbor cannot assist with any emergency supplies.
3. Multiple pipeline breaks occur along a fault line that crosses the system. Repairs will be performed sequentially over 45 days. A phased schedule for repairs is needed along with corresponding operations plans to optimize system performance as each pipeline is put back into service.
4. Two large ground storage tanks are damaged. One will be out of service for two months and the other for three months. Two operations plans are needed to supply water to the system in the most effective manner while the first and then the second tank are under repair.

OGA Formulation & Analysis

The OGA is formulated to search for optimized solutions based on a calibrated model of the existing distribution system. The OGA is linked to the simulation model (in EPANET format) following preparation of an efficient coding structure to fully represent trial solutions in the search.

Decision variables are coded for all the operational and capital improvement choices to be considered. A range of values for each variable is defined. Although the decision variables may differ from one emergency scenario to another, a comprehensive coding is attempted so all choices are available in any OGA run.

Once the initial formulation is complete, a series of OGA runs are conducted. Each scenario is optimized separately to identify feasible operating plans that supply demands while meeting all specified design criteria (as

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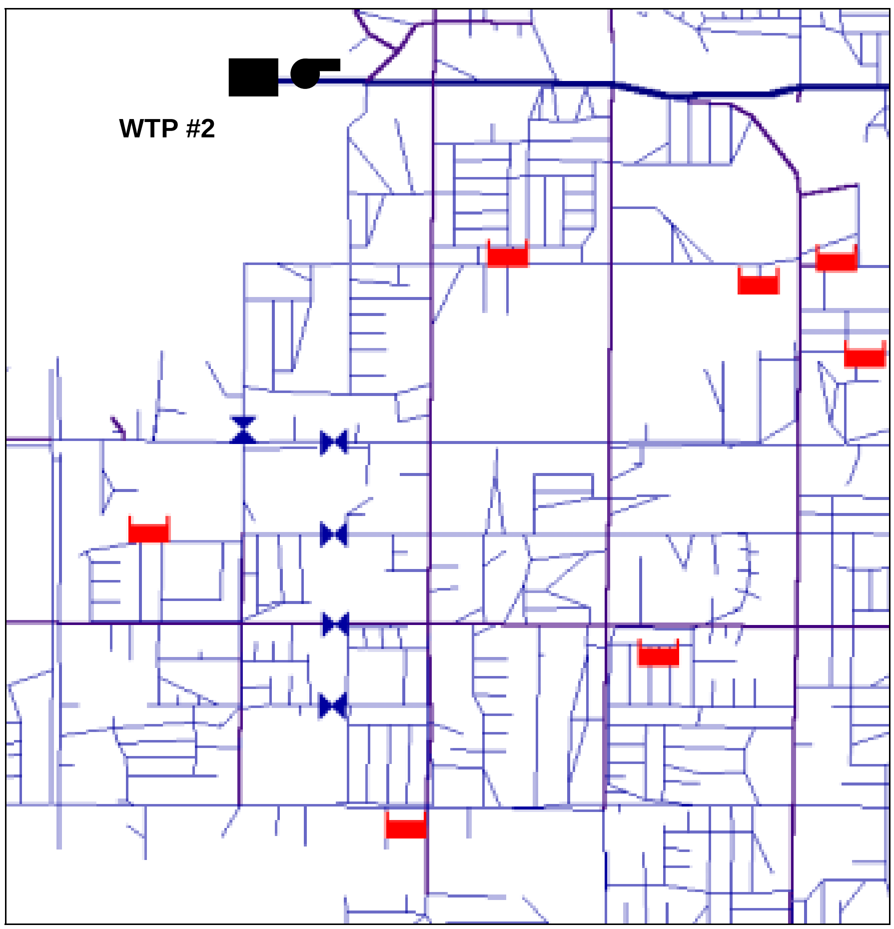

Figure 1. Water utilities need contingency plans in order to respond quickly to the wide range of emergency conditions that could occur in the event of a major earthquake.

defined in the OGA constraints). The preliminary solutions are reviewed to ensure they are reasonable and can be implemented operationally.

If a feasible solution cannot be found for one of the emergency scenarios, then the scenario itself, the allowable operational options and the performance constraints for that particular scenario are reviewed. Perhaps new operational options and/or capital improvement options are added as decision choices for the OGA that will permit the system to operate satisfactorily under the emergency conditions.

If the system still cannot supply the demands at specified pressures, the utility might decide to reduce the level of demands or pressures for the affected areas of the system by imposing water restrictions. The OGA is then re-run with these relaxed constraints to identify alternative operating plans that achieve the best service possible for that severe emergency scenario.

OGA Emergency Planning Results

As results from the OGA runs come in, the utility's planning and operations staff review the proposed operations and capital improvement plans to make sure they are workable for the utility. If new ideas are generated, these are evaluated in the next cycle of OGA runs.

After several cycles, a preferred OGA solution is identified for each emergency scenario. The OGA will have minimized operating and capital costs over the emergency period while detailing how the system should operate to meet the demands and performance criteria. The preferred solutions represent the best of all feasible choices from among the hundred thousand or so alternatives evaluated in each OGA search.

Some of the preferred solutions may include capital improvements. In this case, the OGA will be re-run to see if the improved system could operate satisfactorily for the rest of the emergency demand cases. If all possible operating choices are coded into the OGA, this evaluation could conceivably be handled in a single OGA run where each demand case is analyzed in turn.

Conclusion

As the application of formal optimization techniques become more common in the water industry, certainly emergency planning will be an area which gets a lot of attention. If a water utility was so inclined, it would be straightforward to develop in advance a set of emergency operations guidelines for a range of conditions. Such an effort might also have the added benefit of optimizing current system operations to minimize water purchase and operating costs.

One caveat the reader should keep in mind regarding optimization analysis using the OGA or any other optimization technique: no matter how powerful this technology appears, it is simply a tool that a planner or modeler can call on to find better and cheaper solutions faster. Optimization does not substitute for experience and engineering judgement, but instead it complements them.

Update on the Future of Computing

At Optimatics/Frey, we continue to be fascinated by stories on DNA computing. In the January 12th Christian Science Monitor, Alex Salkever describes research underway at the University of Wisconsin. DNA is powering a dime-sized "biocomputer" to solve basic math problems. The computer is described as a forest of DNA tethered to a piece of gold plated glass.

DNA computers could have a nearly limitless ability to store and analyze information. "The potential of DNA-based computation lies in the fact that DNA has a gigantic memory capacity and also in the fact that the biochemical operations dissipate so little energy," says University of Rochester scientist Mitsunori Ogihara.

DNA represents information in strings of four nucleic acids, rather than strings of zeroes and ones as in silicon computers. Data is manipulated through biochemical reactions that alter or match up pairings of nucleic acids.

As far back as 1994, Professor Leonard Adelman at USC used DNA to solve the classic "traveling salesman" problem. This type of problem is particularly difficult since each added variable exponentially increases the complexity of the problem, (just like it does for a water distribution modeling problem).

Calendar of Events

Today	PowerPoint slideshow* at *www.frey-water.com*
April 4-7	TX Section AWWA Conference in Dallas
April 16-19	AWWA IMTech Conference in Seattle
April 24-27	CA-NV AWWA Conference in Monterey
June 11-15	AWWA Annual Conference in Denver

Optimatics/Frey staff will present or exhibit at each event.

* Slideshow on GA optimization is available for download.

For information, contact Frey Water Engineering, Inc., 121 South Chestnut Ave., Suite 200 Arlington Heights, IL 60005-1817 • Phone (847) 670-7970 • Fax (847) 670-7973 • E-mail: info@frey-water.com. Also, please visit our website at *www.frey-water.com*.

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FREY Water Engineering

The Optimatics Letter
c/o Frey Water Engineering, Inc.
121 South Chestnut Ave., Suite 200
Arlington Heights, IL 60005-1817
www.frey-water.com

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Fax a copy of this page to 847-670-7973 or e-mail the editor at jfrey@frey-water.com