The Optimatics Letter

Issue No. 16: April-June 2002 *Advances in Optimization for Water Distribution System Design & Operations*

Optimal Staging of Capital Works Using GA

After agreement on the recommended capital improvements in a Master Plan study, a water utility is faced with the question of when to actually implement the improvements. The improvements may include upgrading existing water treatment plants and pump stations, adding new water sources, and adding new (or replacing/rehabilitating) pipes, tanks, pumps and valves.

The water utility will want to schedule the improvements over a specified planning period in an attempt to keep pace with projected future demand increases throughout the system. The output of a scheduling exercise is a plan that identifies which facilities should be built, installed or replaced for selected time periods.

Typically, capital improvement plans (CIPs) are prepared based on five-year time intervals. The initial five-year plan is likely to be implemented unchanged, while later plans are reviewed periodically in response to changing demands and system performance.

Formulating a Staging Optimization

The theoretical problem of developing plans for the optimal staging of capital works for water distribution systems is extremely complex. Consider, for example, a year 2022 master plan solution for which you'd like to stage the capital improvements over four periods: 2003-2007, 2008-2012, 2013-2017 and 2018-2022.

The correct way formulate this optimization problem would be to minimize the present value of all construction, operation, maintenance and treatment costs for all of the implementation stages. In other words, you would need to solve the following four sub-problems simultaneously:

1. select additions to the existing network to satisfy the 2007 loading patterns,
2. select additions to the network (with the 2007 additions included) to satisfy the 2012 loading patterns,
3. select additions to the network (with the 2007 and 2012 additions included) to satisfy the 2017 loading patterns, and
4. select additions to the network (with all previous additions included) to satisfy the 2022 loading patterns.

This turns out to be a very large problem that is probably unmanageable with the current state of technology for optimizing systems.

A Practical Optimization Approach

A practical formulation of the optimal staging problem is possible using an approach that can be called the "Build to Target" method. The idea is to optimize the system first for the final or "target" year (in this case 2022). The solution to this first optimization problem identifies all of the facilities that will need to be constructed during the planning period.

A series of sub-problems are then optimized, one for each intermediate planning stage, to identify when each facility should be built. For these sub-problems, each decision variable is either 1 or 0. A '1' indicates that the corresponding facility is planned for construction during that time period; a '0' indicates that it is not. The sizes of all facilities are set at the sizes identified in the solution for the "target" year.

(Continued on page 2)

The "Build to Target" staging approach was used to optimize the year 2022 Reno-Sparks Water Supply and Transmission System Expansion Plan

Three New Studies Underway this Quarter

*The **City of Waco** (Texas), **Bonita Springs Utilities** (Florida) and **Harford County Public Works** (Maryland) have recently initiated system-wide water master plans. Each of the water utilities has opted to incorporate genetic algorithm (GA) optimization analysis as an integral part of their study. The obvious aim in applying GA optimization is to minimize the capital cost of improvements to year 2020 or 2030, while at the same time improving system reliability and system hydraulic performance.*

Optimatics/Frey Water Engineering will apply the Optimatics GA (OGA) to the system hydraulic models to identify alternative near-optimal plans for Waco, Bonita Springs, and Harford County. CH2M HILL is the lead firm on the studies and is responsible for preparing the hydraulic models, among other tasks.

Published jointly by Frey Water Engineering, Inc., USA and Optimatics Pty Ltd, Australia, consultants specializing in OGA optimization.

Since the sizes of the facilities do not have to be selected for the earlier years, the solution space of the GA for these sub-problems will be substantially smaller than the initial "target" year problem. For example, if there are 200 decision variables for the target year, each of which can take on 6 values, the size of the solution space is 6^{200} or 4.27×10^{155}. Suppose only 100 of these decision variables are used in the final plan. The size of the search space for the first planning stage (i.e., 2003-2007) is then 2^{100} or 1.27×10^{30}.

For the second planning stage, all options selected in the first planning stage are locked in place and a choice is made from among the remaining options. The search space in this case is therefore smaller. A similar situation applies for the third planning stage.

One shortcoming of the Build to Target approach is that the improvement size choices are limited to the optimized sizes selected for the target year condition. The approach does not allow for smaller pipes to be selected in the first planning stage that could later be paralleled as demands increase. Careful review of the staged improvement plans is thus necessary to consider such refinements for each staged plan.

Reno-Sparks Master Plan GA Study

Optimatics/Frey recently completed a Master Plan of the Reno-Sparks water system for the Truckee Meadows Water Authority (formerly the Sierra Pacific Power Company). The water system supplies approximately 200,000 people in Reno-Sparks, Nevada. The aim of the study was to apply the Optimatics GA (OGA) to optimize the system expansion plans for the major gravity zones of the Reno-Sparks system to the year 2022. Once an optimized 2022 plan was agreed upon, the OGA would be used to develop phased improvement plans.

Originally, a Stoner SWS hydraulic model of the system with 2,200 pipes was supplied to Optimatics for the development of the OGA. By the time the staging study commenced, however, TMWA had developed an 11,500 pipe H2ONet model of the system. This was subsequently converted into an EPANET model for use with the OGA.

The objective of the 2022 study was to minimize the capital cost of system improvements and the present value of on-going costs such as water production costs while ensuring that the system satisfied certain

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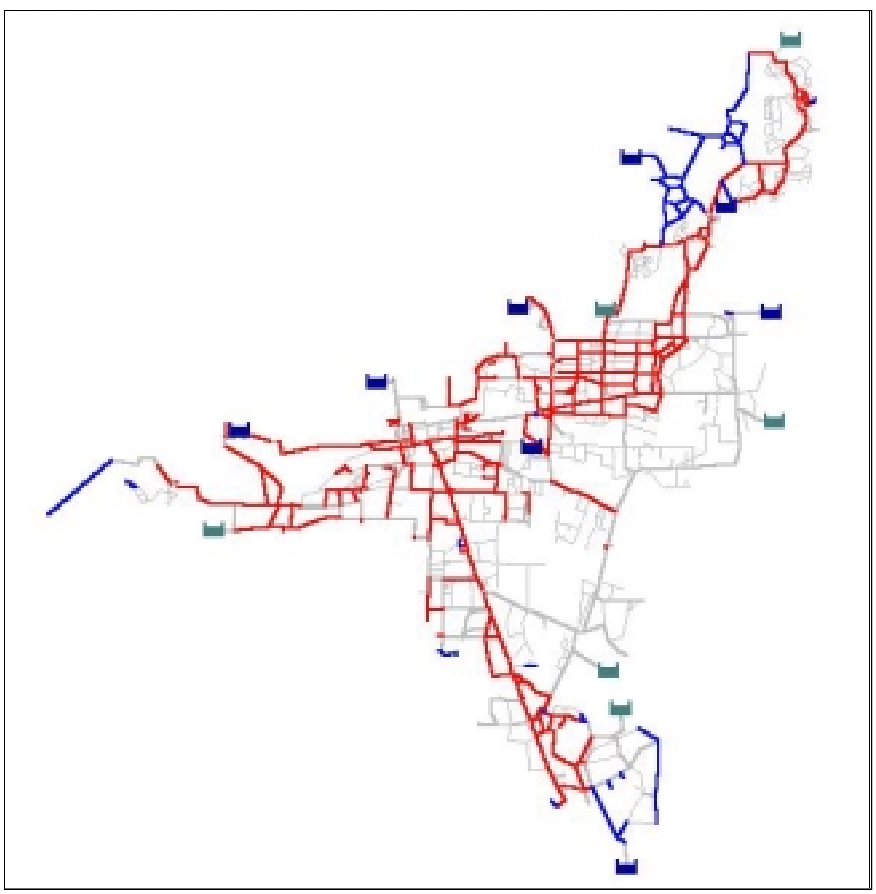

Figure 1. Reno-Sparks Water Supply & Transmission System—Layout shows 670 essential and non-essential (zero size allowed) pipe choices considered in GA optimization of year 2022 plan.

performance requirements. The decision variables included: 670 new pipes choices, settings for 36 regulating valves, the status of 19 pumps, and the production rate at 26 wells. The available sizes considered by the OGA for new pipes ranged from 6" to 72". A layout of the system showing the allowable new and parallel pipe options is given in Figure 1.

The system was planned to meet maximum day demands. System performance requirements included: minimum 40 psi pressure at demand nodes, maximum 125 psi pressure, maximum velocity of 8 ft/s, minimum HGLs at wholesale supply points, minimum suction pressure at several pump stations, and maximum inflow and outflow rates for all reservoirs and tanks.

Optimized Staging for Reno-Sparks

Using the OGA solution as a base, TMWA applied some additional constraints related to preferred pipe routes to develop a final 2022 solution. Figure 2 (see back cover) shows the "target year" plan with all of the selected pipes that will be needed to meet the projected year 2022 demands.

The final plan shown in Figure 2 was the basis for the subsequent staging study optimization performed using the Build to Target approach described above. The figure depicts the staging of improvements for each five-year time step. The 2002 improvements were either in place or committed by completion of the GA study in November 2001.

The capital costs for each five-year time step are shown below. The present values of costs have been calculated for a base year of 2002 using various discount rates (i).

Implementation Stage	Capital Cost
2002 improvements	$2,105,668
2003-2007 improvements	$10,128,060
2008-2012 improvements	$7,967,907
2013-2017 improvements	$18,715,584
2018-2022 improvements	$3,982,210
Total	$42,899,429
Present value at i=5%	$9,231,827
Present value at i=7%	$8,103,777
Present value at i=10%	$6,831,659

Some Final Thoughts

Optimizing the staging of the agreed capital improvements identified in a Master Plan is a complex problem. The Build to Target method described in this article using GA optimization represents a practical approach that proved to work well on the Reno-Sparks water system expansion plan.

Another staging optimization approach that has been investigated using GA is the Build Up approach. In this case, the optimization is performed on each time period in succession from the first to the last. Each subsequent stage is optimized with all of the decisions from the previous stages locked in place.

Depending on the circumstances, there may be advantages to the Build Up approach versus the Build to Target approach of optimizing staging. Both approaches could be applied and the results then compared. It is pretty straightforward to perform a second analysis once the intermediate demand cases are set up.

If the list of Master Plan improvements is relatively short and simple, it won't be necessary to optimize the staging. Staging of the improvements can instead be developed by simply checking the performance of the system for intermediate demands with a series of simulation runs.

Correction to Optimatics Letter #15

Dr. Lippai has pointed out that the Lippai, Heaney & Laguna $38.13M and $37.83M solutions to the New York City Tunnels problem (published in 1999) are, in fact, fully feasible solutions when evaluated using EPANET Version 1.x. Sorry for neglecting to mention this fact in our last newsletter.

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The Optimatics Letter is published quarterly and is intended to provide information of value to the water industry.

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Advances in Optimization for Water Distribution System Design & Operations

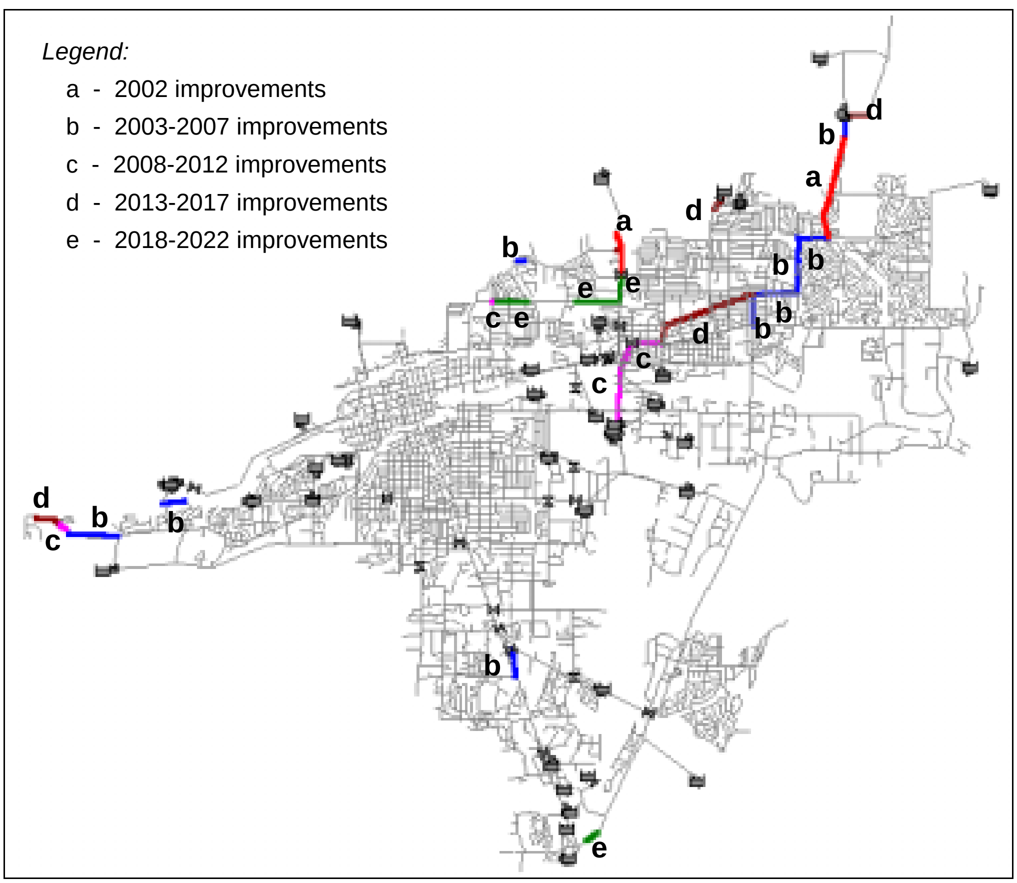

Figure 2. Optimized Staging of Capital Improvements for Reno-Sparks Water System Year 2022 Expansion Plan—A “Build to Target” GA optimization approach was used to stage $43 million in recommended capital works.