By William J. Browning

Editor's note: This is another in a series of articles profiling members of the INFORMS Roundtable.

Applied Mathematics Offers Wide Range of Services

Consulting firm develops and implements mathematical models for everything from submarine warfare to agriculture.

Virginia Class ship control station.

Applied Mathematics, Inc., is a privately held technical consulting firm with offices in Gales Ferry, Conn., near the U.S. Naval Submarine Base New London. Also close by on the Thames River are the Electric Boat Company, a builder of nuclear submarines; the U.S. Coast Guard Academy and the Coast Guard Research and Development Center; and Pfizer Central Research facilities.

Applied Mathematics develops and implements mathematical models to help our clients better understand complex systems in order to improve system performance. Since 1980, we have completed more than 120 research and development projects for U.S. and foreign government agencies and industry. Areas of applications include submarine warfare, search and tracking, search and rescue, clinical informatics and vineyard analytics. Algorithms developed by Applied Mathematics are in use on U.S. and U.K. submarines. In addition, we occasionally design, build and test prototype systems. Examples include a portable launch system for analog torpedoes, a micro-fluidic actuation system for active flow control of an airfoil and an environmental sensor for use by a submarine.

Every Applied Mathematics staff member has a degree in mathematics, physics or computer science, with the majority having M.S. and Ph.D. degrees. Mindful of Isaac Newton's counsel that "it is better to send mathematicians to sea to collect data than to send data collected at sea to mathematicians ashore," our staff have participated as test directors and technical observers in more than 100 operations and tests conducted at sea on U.S. and U.K. submarines and naval vessels and military aircraft throughout the world. In addition, for more than 30 years, our mathematicians and physicists have been embedded at a submarine squadron working closely with submarine officers in developing and evaluating tactics.

In our technical reports for our clients we include all the data and the assumptions made in the analysis, and we describe the models and algorithms in detail so that the client can obtain a second opinion should he or she desire. We also regularly conduct pro bono projects; our staff members volunteer their time and services to numerous professional and non-profit organizations.

Following are brief descriptions of three application areas in which we have worked for many years.

Submarine Tactics. The field of operations research began with operational analysis of anti-submarine warfare during the Battle of the Atlantic in World War II. A good reference for this fascinating history is "Slide Rules and Submarines," by Montgomery Meigs, an historian and Army general.

The role played by operations analysis in World War II was not lost on the U.S. Navy. Throughout the long Cold War between Soviet and U.S. submarines, Ph.D. analysts from Applied Mathematics and other organizations were embedded in Navy fleet ASW and submarine commands.

Some of the submarine tactics areas we have worked on include submarine search tactics (e.g., choice of speed, track and depth), target tracking using passive sonar, torpedo evasion tactics, submarine evasion tactics, optimal allocation of sonar system signal processing and torpedo and cruise missile tactics. Mathematical methods we have used include simulation, game theory, control theory, optimization and statistical estimation.

One important assignment for more than 20 years was the Submarine Search Manual. This manual gives search speed, track and depth guidance for a submarine when conducting a search for another submarine.

Search is a basic activity of all organisms – the search for food and the search for shelter from predators. The science of how organisms search for prey is called foraging by biologists. Three types of searches are considered by biologists – cruise, saltatory and ambush.

Energy demands – e.g., lack of endurance and the "prey handling" problem, e.g., what to do when you catch the prey, which is often a matter of life and death for both parties – dictate the type of search that organisms conduct.

A cruise, or constant speed search, maximizes range at time of detection and is used when the large sweep rates possible from a saltatory search are either not available due to short detection ranges or not necessary due to a small search area. Sharks and hawks use a cruise search strategy. A saltatory, or sprint and drift, search is used when the search area is large, detection ranges are long and the prey is not uniformly distributed. The e coli bacteria and some fish use a saltatory search.

An ambush, or barrier search, is used when the track of a target can be predicted. Scorpions and snakes use an ambush search.

All About the Roundtable

INFORMS has two types of members: individual and institutional. The latter (usually a company) joins by joining the INFORMS Roundtable and appointing as its representative the person in overall charge of O.R.

The Roundtable has been very active since its founding in 1982, with three meetings each year and much communication in between. It, its member institutions and its member representatives take a strong interest in how INFORMS serves the needs of practitioners, and have undertaken many initiatives and provided many services toward this end. These involve, for example, public awareness of O.R., both of the annual INFORMS conferences, continuing professional education, one of the prizes and various committees.

In addition, the Roundtable has an advisory responsibility to INFORMS. One bylaw states that it "... shall regularly share with INFORMS leadership its views, its suggested initiatives and its implementation plans on the important problems and opportunities facing operations research and the management sciences as a profession and on the ways in which INFORMS can deal proactively with those problems and opportunities ..." By tradition, it meets with the newly elected INFORMS president-elect each spring to discuss practice-related topics of interest to him or her, and with the entire INFORMS Board each fall to discuss topics of mutual concern.

The Roundtable membership comprises about 50 organizations. Further information is available at http://roundtable.informs.org.

This series of articles aims to share with the INFORMS membership at large some information and insights into how O.R. is carried on in practice today.

Cabernet Sauvignon grape clusters, Napa Valley, Calif.

Each species has evolved to search in only one way except the nuclear submarine. A nuclear submarine with its modern long-range sensors and its unlimited source of energy is unique in that it can and does conduct each of these distinct types of searches for its prey – ships and submarines.

Ocean Surface Current Estimation. A core mission of the Coast Guard is search and rescue (SAR) of people in distress at sea. The Coast Guard conducts more than 50,000 SAR cases annually.

Mathematically, a search consists of a probability distribution in space and time of the search object, the detection range of the sensor(s) and constraints on search effort, either number of searchers, time or both. The problem is to optimize some measure of effectiveness, such as probability of detecting the person while still alive subject to constraints on search effort. Because SAR detection ranges are usually very short and the ocean is so large, it is important to obtain as good an estimate as possible on where the search object may be drifting in the ocean due to the effects of wind and surface current.

One method used in a large area open ocean search is to drop self-locating data marker buoys (SLMDB) from an aircraft at the last known position of the search object. These buoys then periodically report their GPS position via satellite.

When measurements are scarce, expensive or difficult to obtain, it is important to maximize the information obtained from the measurements. The more useful the mathematical concept, the more names it has. Kriging, geostatistics, objective analysis, weighted least squares and optimal interpolation all refer to the same mathematical concept that is used in this and many other applications.

For the Coast Guard, we developed time-dependent kriging algorithms to blend the reported GPS positions of the buoys to obtain a surface current velocity vector field and associated uncertainty. The velocity field was then used with the Fokker-Planck equation to propagate in time the area of uncertainty for possible target locations. This model resulted in a significant improvement in the probability distribution of the search object compared to the procedures that had been in use.

Grape Crop Estimation. More than 23,000 farms grow grapes in the United States with close to a million grape-bearing acres and a total crop value in excess of $3.5 billion in 2005. About 90 percent of the grape crop in the United States is grown in California. However, grape production in the U.S. is less than 5 percent of the world production. There are almost 5,000 bonded wineries in the U.S., located in all 50 states. The retail value of wine produced in the U.S. was $24 billion in 2005.

The inability to accurately forecast grape crop yield costs the wine and grape industries hundreds of million of dollars a year. In recent years, 30 percent to 50 percent errors in yield estimates have occurred.

Accurate and timely forecasts of wine grape crop yields are required for the efficient operation of a modern winery. Yield estimates are used throughout the winery to support a wide range of activities including scheduling labor in the vineyard; procuring cooperage, labor and equipment for crush; and developing marketing strategies. Yield estimates are needed during the dormant season – late fall – and during the growing season – at bloom, mid-season and at harvest.

The increased use of mechanical harvesters in California, currently more than 60 percent of the acreage, has also increased the demand for more accurate yield estimates in order to better manage harvest.

Yield components from the current growing season such as cluster count, cluster size, berry set and berry weight are used to estimate yield using statistical methods. A commonly used method is cluster counting. Cluster counts sampled statistically prior to bloom are multiplied by an estimate of cluster weight at harvest to predict yield per vine.

We have been working with growers and research viticulturists in California to improve the sampling and kriging algorithms used to estimate crop yield.

Using GPS-equipped mechanical harvesters, technicians have recently conducted precision harvesting experiments on California vineyards. The vineyard is sampled using a portable Near Infrared Spectrometer to prepare a quality map of the vineyard prior to harvest. The mechanical harvester then automatically segregates the fruit into separate gondolas. We are currently analyzing data from these experiments.

In summary, the ease with which massive amounts of data can be automatically recorded today – and the availability of powerful and inexpensive computer processing – offers the promise for significant advances and widespread use of mathematical modeling in areas as diverse as agriculture and submarine warfare. ORMS

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