IDA | Research Summary

A Statistical Solution to a Physics Problem

IDA's Welch Award annually recognizes the best external publication by IDA researchers. Last year marked the 10th anniversary of the award, named for retired U.S. Air Force General Larry D. Welch, who served as president of IDA from 1990 to 2003 and again from 2006 to 2009. This summary is the eighth in a series reflecting on the 10 winning publications since the award's inception in 2011. The Welch Award winner for best external publication in 2014 was "Mixed Models Analysis of Radar Residuals Data."

Before their paper was published in *IEEE Access* in 2013, then-IDA researchers Carl Clifford Gaither III, Christopher R. Jackson, Dawn C. Foley Loper, and Jasmina Marsh—all members of the Operational Evaluation Division of the Systems and Analyses Center—had historically combined their expertise on projects related to ballistic missile defense systems. Loper, Jackson, and Gaither had collaborated on projects of the sort beginning in 2004, subsequently adding Marsh to the mix starting in 2010.

As the paper's title implies, the authors applied a mixed models approach to the analysis of radar tracking residuals from calibration satellites observed by the Cobra Dane radar, part of the Defense Department's missile defense system. The analysis found a time-dependent bias in the azimuth residuals.

While her coauthors have since retired from IDA, Loper remains. She recently reflected on the incentive to address biases in radar observation in 2012, explaining how radar bias has always

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been a "fact-of-life" in sensor analysis. She explained that as the Missile Defense Agency developed and fielded more sensors, the biases (and other inaccuracies) became more important to understand. A missile defense system requires accurate correlation between tracks from multiple sensors if it is to develop a defense plan that neither over- nor underestimates the threats to be countered. Eventually, Loper and her colleagues would help to provide a great deal of this critical insight into radar bias by coming up with a novel solution to an age-old problem. In the case of the Cobra Dane radar, the problem can be traced back to late 2004 and 2005, when evaluations of the historic radar's performance pointed to a potential bias in its observations. Little was known then about causes of the bias.

At the center of the authors' research were residuals or data points expressing the discrepancies between locations of calibration satellites (used as reference points) and the Cobra Dane radar's reported observations of the satellite positions. The residuals marked the differences when these observations were compared, and they showed a consistent transition from negative values to positive values, or a bias, rather than an equal, random dispersion of positive and negative values across the face of the radar.

Where the research strayed from a traditional approach in determining the root cause of the bias was in the model that was used. A statistical model typically used in social science fields known as a "mixed model" was ultimately applied when the group reasoned that, given their lack of information about the extent of the varying physical qualities of the calibration satellites, a physics-based model seemed ill-suited for the job.

As opposed to a physics model, the mixed model successfully accounted for the numerous, random idiosyncrasies of calibration satellites all at once, including their locations, their shapes, and other unknown differences. By controlling for these random satellite effects, the group was able to account for the variation in residuals, and specifically in the azimuth residuals, to a greater extent than ever before.

Loper attested to the Welch Award being a "satisfying" and "rare chance" to gain recognition for her work at IDA that was simultaneously sharable in the broader scientific community.

She also explained the direction in which the research has gone since then, especially as more sensors are being fielded today. The bias of missile defense radars remains a part of the Defense Department's oversight of the missile defense system. The Missile Defense Agency is currently implementing an active bias-monitoring system for several of the radars, which IDA is helping to assess.

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