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Modeling Forum

Results of the 2010 Mathematical Contest in Modeling

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Introduction

A total of 2,254 teams of undergraduates from hundreds of institutions and departments in 14 countries, spent a weekend in February working on applied mathematics problems in the 26th Mathematical Contest in Modeling (MCM)®.

The 2010 MCM began at 8:00 P.M. EST on Thursday, February 18, and ended at 8:00 P.M. EST on Monday, February 22. During that time, teams of up to three undergraduates researched, modeled, and submitted a solution to one of two open-ended modeling problems. Students registered, obtained contest materials, downloaded the problem and data, and entered completion data through COMAP's MCM Website. After a weekend of hard work, solution papers were sent to COMAP on Monday. Two of the top papers appear in this issue of *The UMAP Journal*, together with commentaries.

In addition to this special issue of *The UMAP Journal*, COMAP has made available a special supplementary *2010 MCM-ICM CD-ROM* containing the press releases for the two contests, the results, the problems, and original versions of the Outstanding papers. Information about ordering the CD-ROM is at `http://www.comap.com/product/cdrom/index.html` or from (800) 772–6627.

Results and winning papers from the first 25 contests were published in special issues of *Mathematical Modeling* (1985–1987) and *The UMAP Journal* (1985–2009). The 1994 volume of *Tools for Teaching*, commemorating the tenth anniversary of the contest, contains the 20 problems used in the first 10 years of the contest and a winning paper for each year. That volume and the special

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MCM issues of the *Journal* for the last few years are available from COMAP. The 1994 volume is also available on COMAP's special *Modeling Resource* CD-ROM. Also available is *The MCM at 21* CD-ROM, which contains the 20 problems from the second 10 years of the contest, a winning paper from each year, and advice from advisors of Outstanding teams. These CD-ROMs can be ordered from COMAP at `http://www.comap.com/product/cdrom/index.html`.

This year, the two MCM problems represented significant challenges:

- Problem A, "The Sweet Spot," asked teams to explain why the spot on a baseball bat where maximum power is transferred to the ball is not at the end of the bat and to determine whether "corking" a bat (hollowing it out and replacing the hardwood with cork) enhances the "sweet spot" effect.
- Problem B, "Criminology," asked teams to develop geographical profiling to aid police in finding serial criminals.

In addition to the MCM, COMAP also sponsors the Interdisciplinary Contest in Modeling (ICM)® and the High School Mathematical Contest in Modeling (HiMCM)®:

- The ICM runs concurrently with MCM and for the next several years will offer a modeling problem involving an environmental topic. Results of this year's ICM are on the COMAP Website at `http://www.comap.com/undergraduate/contests`. The contest report, an Outstanding paper, and commentaries appear in this issue.
- The HiMCM offers high school students a modeling opportunity similar to the MCM. Further details about the HiMCM are at `http://www.comap.com/highschool/contests`.

2010 MCM Statistics

- 2,254 teams participated
- 15 high school teams (<1%)
- 358 U.S. teams (21%)
- 1,890 foreign teams (79%), from Australia, Canada, China, Finland, Germany, Indonesia, Ireland, Jamaica, Malaysia, Pakistan, Singapore, South Africa, United Kingdom
- 9 Outstanding Winners (<0.5%)
- 12 Finalists (0.5%)
- 431 Meritorious Winners (19%)
- 542 Honorable Mentions (24%)
- 1,245 Successful Participants (55%)

Problem A: The Sweet Spot

Explain the "sweet spot" on a baseball bat. Every hitter knows that there is a spot on the fat part of a baseball bat where maximum power is transferred to the ball when hit. Why isn't this spot at the end of the bat? A simple explanation based on torque might seem to identify the end of the bat as the sweet spot, but this is known to be empirically incorrect. Develop a model that helps explain this empirical finding.

Some players believe that "corking" a bat (hollowing out a cylinder in the head of the bat and filling it with cork or rubber, then replacing a wood cap) enhances the "sweet spot" effect. Augment your model to confirm or deny this effect. Does this explain why Major League Baseball prohibits "corking"?

Does the material out of which the bat is constructed matter? That is, does this model predict different behavior for wood (usually ash) or metal (usually aluminum) bats? Is this why Major League Baseball prohibits metal bats?

Problem B: Criminology

In 1981, Peter Sutcliffe was convicted of 13 murders and subjecting a number of other people to vicious attacks. One of the methods used to narrow the search for Mr. Sutcliffe was to find a "center of mass" of the locations of the attacks. In the end, the suspect happened to live in the same town predicted by this technique. Since that time, a number of more sophisticated techniques have been developed to determine the "geographical profile" of a suspected serial criminal based on the locations of the crimes.

Your team has been asked by a local police agency to develop a method to aid in their investigations of serial criminals. The approach that you develop should make use of at least two different schemes to generate a geographical profile. You should develop a technique to combine the results of the different schemes and generate a useful prediction for law enforcement officers. The prediction should provide some kind of estimate or guidance about possible locations of the next crime based on the time and locations of the past crime scenes. If you make use of any other evidence in your estimate, you must provide specific details about how you incorporate the extra information. Your method should also provide some kind of estimate about how reliable the estimate will be in a given situation, including appropriate warnings.

In addition to the required one-page summary, your report should include an additional two-page executive summary. The executive summary should provide a broad overview of the potential issues. It should provide an overview of your approach and describe situations when it is an appropriate tool and situations in which it is not an appropriate tool. The executive summary will be read by a chief of police and should include technical details appropriate to the intended audience.

The Results

The solution papers were coded at COMAP headquarters so that names and affiliations of the authors would be unknown to the judges. Each paper was then read preliminarily by two "triage" judges at either Appalachian State University (Sweet Spot Problem) or at the National Security Agency (Criminology Problem). At the triage stage, the summary and overall organization are the basis for judging a paper. If the judges' scores diverged for a paper, the judges conferred; if they still did not agree, a third judge evaluated the paper.

Additional Regional Judging sites were created at the U.S. Military Academy and at the Naval Postgraduate School to support the growing number of contest submissions.

Final judging took place at the Naval Postgraduate School, Monterey, CA. The judges classified the papers as follows:

	Outstanding	Finalist	Meritorious	Honorable Mention	Successful Participation	Total
Sweet Spot Problem	4	5	180	217	533	939
Criminology Problem	5	7	251	325	712	1300
	9	12	431	542	1245	2239

We list here the 9 teams that the judges designated as Outstanding; the list of all participating schools, advisors, and results is at the COMAP Website.

Outstanding Teams

Institution and Advisor	**Team Members**
Sweet Spot Problem	
"An Optimal Model of 'Sweet Spot' Effect"	
Huazhong University of Science and Technology	Zhe Xiong
Wuhan, Hubei, China	Qipei Mei
Liang Gao	Fei Han
"The Sweet Spot: A Wave Model of Baseball Bats"	
Princeton University	Yang Mou
Princeton, NJ	Peter Diao
Robert Calderbank	Rajib Quabili

"Brody Power Model: An Analysis of Baseball's 'Sweet Spot'"
U.S. Military Academy — David Covell
West Point, NY — Ben Garlick
Elizabeth Schott — Chandler Williams

"An Identification of 'Sweet Spot'"
Zhejiang University — Cong Zhao
Hangzhou, China — Yuguang Yang
Xinxin Xu — Zuogong Yue

Criminology Papers

"Predicting a Serial Criminal's Next Crime Location Using Geographic Profiling"
Bucknell University — Bryan Ward
Lewisburg, PA — Ryan Ward
Nathan C. Ryan — Dan Cavallaro

"Following the Trail of Data"
Rensselaer Polytechnic Institute — Yonatan Naamad
Troy, NY — Joseph H. Gibney
Peter R. Kramer — Emily P. Meissen

"From Kills to Kilometers: Using Centrographic Techniques and Rational Choice Theory for Geographical Profiling of Serial Killers"
Tufts University — Daniel Brady
Medford, MA — Liam Clegg
Scott MacLachlan — Victor Minden

"Centroids, Clusters, and Crime: Anchoring the Geographic Profile of Serial Criminals"
University of Colorado—Boulder — Anil S. Damle
Boulder, CO — Colin G. West
Anne M. Dougherty — Eric J. Benzel

"Tracking Serial Criminals with a Road Metric"
University of Washington — Ian Zemke
Seattle, WA — Mark Bun
James Allen Morrow — Jerry Li

Awards and Contributions

Each participating MCM advisor and team member received a certificate signed by the Contest Director and the appropriate Head Judge.

INFORMS, the Institute for Operations Research and the Management Sciences, recognized the teams from Princeton University (Sweet Spot Problem) and Tufts University (Criminology Problem) as INFORMS Outstanding teams and provided the following recognition:

- a letter of congratulations from the current president of INFORMS to each team member and to the faculty advisor;
- a check in the amount of $300 to each team member;
- a bronze plaque for display at the team's institution, commemorating team members' achievement;
- individual certificates for team members and faculty advisor as a personal commemoration of this achievement; and
- a one-year student membership in INFORMS for each team member, which includes their choice of a professional journal plus the *OR/MS Today* periodical and the INFORMS newsletter.

The Society for Industrial and Applied Mathematics (SIAM) designated one Outstanding team from each problem as a SIAM Winner. The teams were from Huazhong University of Science and Technology (Sweet Spot Problem) and Rensselaer Polytechnic Institute (Criminology Problem). Each of the team members was awarded a $300 cash prize, and the teams received partial expenses to present their results in a special Minisymposium at the SIAM Annual Meeting in Pittsburgh, PA in July. Their schools were given a framed hand-lettered certificate in gold leaf.

The Mathematical Association of America (MAA) designated one Outstanding North American team from each problem as an MAA Winner. The teams were from the U.S. Military Academy (Sweet Spot Problem) and the University of Colorado—Boulder (Criminology Problem). With partial travel support from the MAA, the teams presented their solution at a special session of the MAA Mathfest in Pittsburgh, PA in August. Each team member was presented a certificate by an official of the MAA Committee on Undergraduate Student Activities and Chapters.

Ben Fusaro Award

One Meritorious or Outstanding paper was selected for each problem for the Ben Fusaro Award, named for the Founding Director of the MCM and awarded for the seventh time this year. It recognizes an especially creative approach; details concerning the award, its judging, and Ben Fusaro are in

Vol. 25 (3) (2004): 195–196. The Ben Fusaro Award winners were Princeton University (Sweet Spot Problem) and Duke University (Criminology Problem). A commentary on the latter appears in this issue.

Judging

Director
Frank R. Giordano, Naval Postgraduate School, Monterey, CA

Associate Director
William P. Fox, Dept. of Defense Analysis, Naval Postgraduate School, Monterey, CA

Sweet Spot Problem

Head Judge
Marvin S. Keener, Executive Vice-President, Oklahoma State University, Stillwater, OK

Associate Judges
William C. Bauldry, Chair, Dept. of Mathematical Sciences, Appalachian State University, Boone, NC (Head Triage Judge)
Patrick J. Driscoll, Dept. of Systems Engineering, U.S. Military Academy, West Point, NY (INFORMS Judge)
J. Douglas Faires, Youngstown State University, Youngstown, OH
Ben Fusaro, Dept. of Mathematics, Florida State University, Tallahassee, FL (SIAM Judge)
Michael Jaye, Dept. of Mathematical Sciences, Naval Postgraduate School, Monterey, CA
John L. Scharf, Mathematics Dept., Carroll College, Helena, MT (MAA Judge)
Michael Tortorella, Dept. of Industrial and Systems Engineering, Rutgers University, Piscataway, NJ (Problem Author)
Richard Douglas West, Francis Marion University, Florence, SC

Criminology Problem

Head Judge
Maynard Thompson, Mathematics Dept., University of Indiana, Bloomington, IN

Associate Judges
Peter Anspach, National Security Agency, Ft. Meade, MD (Head Triage Judge)
Kelly Black, Mathematics Dept., Union College, Schenectady, NY

Jim Case (SIAM Judge)
William P. Fox, Dept. of Defense Analysis, Naval Postgraduate School, Monterey, CA
Frank R. Giordano, Naval Postgraduate School, Monterey, CA
Veena Mendiratta, Lucent Technologies, Naperville, IL
David H. Olwell, Naval Postgraduate School, Monterey, CA
Michael O'Leary, Towson State University, Towson, MD (Problem Author)
Kathleen M. Shannon, Dept. of Mathematics and Computer Science, Salisbury University, Salisbury, MD (MAA Judge)
Dan Solow, Case Western Reserve University, Cleveland, OH (INFORMS Judge)
Marie Vanisko, Dept. of Mathematics, Carroll College, Helena, MT (Ben Fusaro Award Judge)

Regional Judging Session at U.S. Military Academy

Head Judges
Patrick J. Driscoll, Dept. of Systems Engineering, United States Military Academy (USMA), West Point, NY

Associate Judges
Tim Elkins, Dept. of Systems Engineering, USMA
Darrall Henderson, Sphere Consulting, LLC
Steve Horton, Dept. of Mathematical Sciences, USMA
Tom Meyer, Dept. of Mathematical Sciences, USMA
Scott Nestler, Dept. of Mathematical Sciences, USMA

Regional Judging Session at Naval Postgraduate School

Head Judges
William P. Fox, Dept. of Defense Analysis, Naval Postgraduate School, Monterey, CA
Frank R. Giordano, Naval Postgraduate School, Monterey, CA

Associate Judges
Matt Boensel, Robert Burks, Peter Gustaitis, Michael Jaye, and Greg Mislick
—all from the Naval Postgraduate School, Monterey, CA

Triage Session for Sweet Spot Problem

Head Triage Judge
William C. Bauldry, Chair, Dept. of Mathematical Sciences, Appalachian State University, Boone, NC

Associate Judges
Jeffry Hirst, Greg Rhoads, and Kevin Shirley
—all from Dept. of Mathematical Sciences, Appalachian State University, Boone, NC

Triage Session for Criminology Problem

Head Triage Judge
Peter Anspach, National Security Agency (NSA), Ft. Meade, MD

Associate Judges
Jim Case
Other judges from inside and outside NSA, who wish not to be named.

Sources of the Problems

The Sweet Spot Problem was contributed by Michael Tortorella (Rutgers University), and the Criminology Problem by Michael O'Leary (Towson University) and Kelly Black (Clarkson University).

Acknowledgments

Major funding for the MCM is provided by the National Security Agency (NSA) and by COMAP. Additional support is provided by the Institute for Operations Research and the Management Sciences (INFORMS), the Society for Industrial and Applied Mathematics (SIAM), and the Mathematical Association of America (MAA). We are indebted to these organizations for providing judges and prizes.

We also thank for their involvement and support the MCM judges and MCM Board members for their valuable and unflagging efforts, as well as

- **Two Sigma Investments.** (This group of experienced, analytical, and technical financial professionals based in New York builds and operates sophisticated quantitative trading strategies for domestic and international markets. The firm is successfully managing several billion dollars using highly-automated trading technologies. For more information about Two Sigma, please visit `http://www.twosigma.com` .)
- **Jane Street Capital, LLC.** (This proprietary trading firm operates around the clock and around the globe. "We bring a deep understanding of markets, a scientific approach, and innovative technology to bear on the problem of trading profitably in the world's highly competitive financial markets, focusing primarily on equities and equity derivatives. Founded in 2000, Jane Street employes over 200 people in offices in new York, London, and Tokyo. Our entrepreneurial culture is driven by our talented team of traders and programmers." For more information about Jane Street Capital, please visit `http://www.janestreet.com` .)

Cautions

To the reader of research journals:

Usually a published paper has been presented to an audience, shown to colleagues, rewritten, checked by referees, revised, and edited by a journal editor. Each paper here is the result of undergraduates working on a problem over a weekend. Editing (and usually substantial cutting) has taken place; minor errors have been corrected, wording altered for clarity or economy, and style adjusted to that of *The UMAP Journal*. The student authors have proofed the results. Please peruse their efforts in that context.

To the potential MCM Advisor:

It might be overpowering to encounter such output from a weekend of work by a small team of undergraduates, but these solution papers are highly atypical. A team that prepares and participates will have an enriching learning experience, independent of what any other team does.

COMAP's Mathematical Contest in Modeling and Interdisciplinary Contest in Modeling are the only international modeling contests in which students work in teams. Centering its educational philosophy on mathematical modeling, COMAP uses mathematical tools to explore real-world problems. It serves the educational community as well as the world of work by preparing students to become better-informed and better-prepared citizens.

Editor's Note

The complete roster of participating teams and results has become too long to reproduce in the printed copy of the *Journal*. It can now be found at the COMAP Website, in separate files for each problem:

`http://www.comap.com/undergraduate/contests/mcm/contests/2010/results/2010_MCM_Problem_A.pdf`
`http://www.comap.com/undergraduate/contests/mcm/contests/2010/results/2010_MCM_Problem_B.pdf`