Modeling Forum

Results of the 2003 Interdisciplinary Contest in Modeling

Chris Arney, Director
Dean of the School of Mathematics and Sciences
The College of Saint Rose
432 Western Avenue
Albany, NY 12203
arneyc@mail.strose.edu

Introduction

A total of 146 teams of undergraduates, from 84 institutions in 6 countries, spent the second weekend in February working on an applied mathematics problem in the 5th Interdisciplinary Contest in Modeling (ICM).

This year's contest began at 8:00 P.M. (EST) on Friday, Feb. 6, and ended at 8:00 P.M. (EST) on Monday, Feb. 10. During that time, the teams of up to three undergraduates or high-school students researched and submitted their solutions to an open-ended interdisciplinary modeling problem involving the coordination and management of airport security. After a weekend of hard work, solution papers were sent to COMAP.

The five papers judged to be Outstanding appear in this issue of *The UMAP Journal*. Results and winning papers from the first four contests were published in special issues of *The UMAP Journal* in 1999 through 2002.

In addition to the ICM, COMAP also sponsors the Mathematical Contest in Modeling (MCM), which runs concurrently with the ICM. Information about the two contests can be found at

`www.comap.com/undergraduate/contests/icm`
`www.comap.com/undergraduate/contests/mcm`

The ICM and the MCM are the only international modeling contests in which students work in teams to find a solution.

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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, consumers, and workers.

This year's problem, the Airport Security Problem, which involved understanding, analyzing, and managing baggage screening and flight scheduling at U.S. airports, proved to be particularly challenging in that it contained various data sets to be analyzed, several challenging requirements needing scientific and mathematical connections, and also the ever-present requirements to use creativity, precision, and effective communication. The authors of the problem, operations research analysts and engineers Sheldon Jacobson and John Kobza, were members of the final judging team and their commentary appears in this issue.

All the competing teams are to be congratulated for their excellent work and dedication to scientific modeling and problem solving. This year's judges remarked that the quality of the papers was extremely high, making it difficult to choose the five Outstanding papers.

In 2003 the ICM continued to grow as an online contest, where teams registered, obtained contest instructions, and downloaded the problem through COMAP's ICM Website.

Problem: The Airport Security Problem

Aviation Baggage Screening Strategies: To Screen or Not to Screen, That Is the Question

You are an analysis team in the Office of Security Operations for the Transportation Security Administration (TSA), responsible for the Midwest Region of the United States. New laws will soon mandate 100% screening of all checked bags at the 429 passenger airports throughout the nation by explosive detection systems (EDSs; see Figure 1). EDSs use computed tomography (CT) technology to scan checked bags, similar to how CAT scans are used in hospitals. Using multiple x-rays of each bag, EDSs create three-dimensional images of a bag's content showing the density of each item. This information is utilized to determine whether an explosive device is present. Experimentation with EDSs indicate that each device is operational about 92% of the time and each device can examine between 160 and 210 bags per hour.

The TSA has been actively purchasing EDSs and deploying them at airports throughout the nation. Given that these devices cost nearly $1 million each, weigh as much as eight tons, and cost several thousand dollars to install in an airport, determining the correct number of devices to deploy at each airport and how best to use them (once operational) are important problems.

Currently, manufacturers are not able to produce the expected number of EDSs required to meet the federal mandate of 100% screening of checked luggage. Because of the limited number of EDS machines available, the Director of Airport Security for the Midwest Region (Mr. Sheldon) is not surprised that the TSA is requesting a detailed analysis on the estimated number of EDSs required at all airports. In addition, given the limited space and funds available for each airport, Mr. Sheldon believes that at some point a detailed analysis of emerging technologies will be needed. Promising technologies with more modest space and labor costs will emerge in the coming decade (e.g., x-ray diffraction; neutron-based detection; quadropole resonance; millimeter wave imaging; and microwave imaging).

Task 1

You have been tasked by your Director, Mr. Sheldon, to develop a model to determine the number of EDSs required at two of the largest facilities in the region, Airports A and B, which are described in the Technical Information Sheet (TIS) in **Appendix A**. Carefully describe the assumptions that you make in designing the model and then use your model to recommend the number of EDSs required using the data provided in **Table 1** of the TIS.

Task 2

Prepare a short (one-page) position paper to accompany your model that describes the security-related objectives of the airlines and the constraints that the airlines must work within for the sets of flights described in **Table 1** of the TIS.

Task 3

Since security screening takes time and might delay passengers, the airport managers at Airport A and B request that you develop a model that can help the airlines determine how to schedule the departure of different types of flights within the peak hour. Carefully describe all the assumptions that you make in designing the model and use your model to produce a schedule for the two airports with the data provided in **Table 1**.

Task 4

Based on your analysis, what can you recommend to Mr. Sheldon and the airlines about checked baggage screening for the flights during the peak hours at your two airports?

Task 5

Mr. Sheldon realizes that your work may have national impact and requests that you write a memo explaining how your models can be adapted to determine the number of EDSs and airline scheduling for all 193 airports in the

Midwest Region. He will send the memo along with the models and the analysis to the Director of the Office of Security Operations (his boss) at the TSA and to all security directors of other airports in the region for their comment and possible implementation.

Additional security measures associated with higher risks may require that up to 20% of the passengers will need to have all their checked bags screened through both an EDS and an explosive trace detection (ETD) machine, even though an EDS is 98.5% accurate in identifying explosive devices in checked bags. ETD machines use mass spectrometry technology to detect minute particles of explosive compounds. Each ETD machine costs $45,000 to purchase, however, the labor cost to operate the ETD machine is approximately 10 times that of the EDS. ETD can process 40 to 50 bags per hour; they are operational 98% of the time; and they are 99.7% accurate in identifying explosive materials on checked bags. At this time, ETD machines have not been federally certified, but Mr. Sheldon believes that they will soon be an integral part of national airport security systems.

Task 6

Modify your EDS models to incorporate the use of ETD machines and determine how many ETD machines are needed for Airports A and B and if the schedules need to be changed. Since this information may affect national level decisions, write a memo to the Director of Homeland Security and the Director of TSA with a technical analysis of this enhanced screening policy. Is the cost of such a policy justified in light of the value that it provides? Should the ETDs replace any of the EDS devices?

Task 7

The Director of Homeland Security must also decide how to best fund future scientific research programs. Use your EDS/ETD model to examine the possible effect of changes in the device technology, cost, accuracy, speed, and operational reliability. Include recommendations for the science, technology, engineering, and mathematics (STEM) research areas that will have the biggest impact on security system performance. Add your recommendation to the memo prepared in Task 6.

Appendix A: Technical Information Sheet (TIS)

Although all the flights in **Table 1** depart during a peak hour, their actual departure times are set by the airline when designing their flight schedule. A flight cannot depart until all its checked bags are screened using an EDS. The airline has the flexibility to schedule their flights during the peak hour to avoid undesirable flight delays due to unscreened bags.

Historical data indicates that flights with 85 or fewer seats typically fly with between 70% and 100% of their seats occupied. Flights with between 128 and

Table 1.
Peak-hour flight departures for airports A and B. Note: On average, 2% of flights are cancelled each day.

Type	Seats/flight	Airport A	Airport B
1	34	10	8
2	46	4	6
3	85	3	7
4	128	3	5
5	142	19	9
6	194	5	10
7	215	1	2
8	350	1	1

215 seats typically fly with between 60% and 100% of their seats occupied. Flights with 350 seats typically fly with between 50% and 100% of their seats occupied. Passengers typically arrive for their flight between forty-five minutes and two hours prior to their scheduled departure time. For flights other than shuttles service, airlines claim that 20% of the passengers do not check any luggage, 20% check one bag, and the remaining passengers check two bags.

Preliminary estimates indicate that it will cost $100,000 to modify existing infrastructure (reinforced flooring, etc.) to install each EDS at Airport A and $80,000 to install a device at Airport B.

Figure 1. Explosive Detection System (EDS).

The Results

Solution papers were coded at COMAP headquarters so that names and affiliations of authors would be unknown to the judges. Each paper was read preliminarily by two "triage" judges at the U.S. Military Academy at West Point, NY. 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 on a score, a third judge evaluated the paper.

Final judging took place at the United States Military Academy, West Point, NY. The judges classified the papers as follows:

	Outstanding	Meritorious	Honorable Mention	Successful Participation	Total
Airport Security	5	19	60	62	146

The five papers that the judges designated as Outstanding appear in this special issue of *The UMAP Journal*, together with commentaries by the authors and by one of the judges. We list those teams and the Meritorious teams (and advisors) below; the list of all participating schools, advisors, and results is in the **Appendix**.

Outstanding Teams

Institution and Advisor	Team Members
"Airport Baggage Screening: Optimizing the Implementation of EDS Machines"	
Carroll College	Gary Allen Olson
Helena, MT	Kylan Neal Johnson
Mark R. Parker	Joseph Paul Rasca
"How I Learned to Stop Worrying and Find the Bomb"	
Harvey Mudd College	Tara Martin
Claremont, CA	Gautam Thatte
Hank Krieger	Michael Vrable
"Advancing Airport Security through Optimization and Simulation"	
Humboldt State University	Michelle R. Livesey
Arcata, CA	Carlos A. Diaz
Eileen M. Cashman	Terrence K. Williams

"The Price of Security:
A Cost–Benefit Analysis of
100% Screening of Checked Baggage"

United States Military Academy
West Point, NY
Michael J. Johnson

Kyle Andrew Greenberg
Tate Alan Jarrow
Michael Alan Powell

"Feds with EDS: Searching for the
Optimal Explosive Scanning System"

Wake Forest University
Winston-Salem, NC
Bob Plemmons

Robert T. Haining
Dana M. Lindemann
Neal P. Richardson

Meritorious Teams (19 teams)

Asbury College, Wilmore, KY (Duk Lee)
Beijing Northern Jiaotong University, China (Yingdong Liu)
Beijing University of Posts and Telecommunications, China (Shoushan Luo)
Chongqing University, China (Xiaofan Yang)
Elon University, Elon, NC (Crista Coles)
Harbin Institute of Technology, China (Kean Liu)
Harvey Mudd College, Claremont, CA (Hank Krieger)
Jinan University, China (Daiqiang Hu)
Maggie Walker Governor's School, Richmond, VA (Martha Hicks)
Olin College of Engineering, Needham, MA (Michael Moody)
School of Peking University, China (Yulong Liu)
Trinity University, San Antonio, TX (Allen Holder)
United States Military Academy, West Point, NY (Elizabeth Schott)
United States Military Academy, West Point, NY (Christopher Farrell)
University College Dublin, Ireland (Rachel Quinlan)
University of Science and Technology of Hefei, China (Hong Zhang)
University of Virginia, VA (Julian Noble)
Wake Forest University, Winston-Salem, NC (Hugh Howards)
Zhejiang University, China (Yong He)

Awards and Contributions

Each participating ICM advisor and team member received a certificate signed by the Contest Directors and by the Head Judge. Additional awards were presented to the Humboldt State University team from Institute for Operations Research and the Management Sciences (INFORMS).

Judging

Director
Chris Arney, Dean of the School of Mathematics and Sciences,
The College of Saint Rose, Albany, NY

Associate Directors
Michael Kelley, Dept. of Mathematical Sciences, U.S. Military Academy,
West Point, NY
Gary W. Krahn, Dept. of Mathematical Sciences, U.S. Military Academy,
West Point, NY

Judges
Richard Cassidy, Dept. of Industrial Engineering, University of Arkansas,
Fayetteville, AR
John Kobza, Dept. of Industrial Engineering, Texas Tech University,
Lubbock, TX
Sheldon Jacobson, Dept. of Mechanical and Industrial Engineering,
University of Illinois, Urbana, IL
Frank Wattenberg, Dept. of Mathematical Sciences, U.S. Military Academy,
West Point, NY

Triage Judges
Mike Arcerio, Gabe Costa, Eric Drake, Bill Felhman, Jeff Flemming, Andy Glen, Paul Goethals, Alex Heidenberg, Denise Jacobs, Alan Johnson, Gary Krahn, Rich Laverty, Tom Lainis, Barb Melendez, Chris Moseley, Joe Myers, Mike Phillips, Bart Stewart, Frank Wattenberg, Brian Winkel, Robbie Williams, and Shaw Yoshitani, all of the U.S. Military Academy, West Point, NY.

Source of the Problem

The Airport Security Problem was contributed by Sheldon Jacobson (Dept. of Mechanical and Industrial Engineering, University of Illinois, Urbana, IL) and John Kobza (Dept. of Industrial Engineering, Texas Tech University, Lubbock, TX).

Acknowledgments

Major funding for the ICM is provided by a grant from the National Science Foundation through COMAP. Additional support is provided by the Institute for Operations Research and the Management Sciences (INFORMS).
We thank:

- the ICM judges and ICM Board members for their valuable and unflagging efforts, and
- the staff of the Dept. of Mathematical Sciences, U.S. Military Academy, West Point, NY, for hosting the triage judging and the final judging.

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 of the student papers here is the result of undergraduates working on a problem over a weekend; allowing substantial revision by the authors could give a false impression of accomplishment. So these papers are essentially au naturel. Light editing has taken place: minor errors have been corrected, wording has been altered for clarity or economy, style has been adjusted to that of *The UMAP Journal*, and the papers have been edited for length. Please peruse these student efforts in that context.

To the potential ICM 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.

Editor's Note

As usual, some of the Outstanding papers were several times as long as we can accommodate in the *Journal*; so space considerations forced me to edit the Outstanding papers for length. The code and raw output of computer programs is omitted, the abstract is often combined with the summary, and usually it is not possible to include all of the many tables and figures.

For the Airport Security Problem, the memos of Tasks 2, 5, and 7 from most papers are largely omitted as such and their modeling content folded into the text. Although these memos provide valuable summaries, they do not contain modeling and tend to duplicate conclusions reached in other sections.

In all editing, I endeavor to preserve the substance and style of the paper, especially the approach to the modeling.

—Paul J. Campbell, Editor

Appendix: Successful Participants

KEY:
P = Successful Participation
H = Honorable Mention
M = Meritorious
O = Outstanding (published in this special issue)

INSTITUTION	CITY	ADVISOR	I
ALABAMA			
Athens State University	Athens	M. Leigh Lunsford	P
CALIFORNIA			
California State Polytechnic University	Pomona	Jennifer Switkes	P
Harvey Mudd College	Claremont	Arthur Benjamin	H
		Hank Krieger	O, M
Humboldt State University	Arcata	Eileen M. Cashman	O
Sonoma State University	Rohnert Park	Elaine T. McDonald	P
COLORADO			
Regis University	Denver	Jim Seibert	H, P
University of Colorado	Boulder	Bengt Fornberg	H
ILLINOIS			
Monmouth College	Monmouth	Christopher G. Fasano	P
INDIANA			
Earlham College	Richmond	Mic Jackson	P
KENTUCKY			
Asbury College	Wilmore	David L. Coulliette	H
		Duk Lee	M, H
Bellarmine University	Louisville	William J. Hardin	H
Northern Kentucky University	Highland Heights	Phillip H. Schmidt	H
MASSACHUSETTS			
Olin College of Engineering	Needham	Michael E. Moody	M
MICHIGAN			
East Grand Rapids Public Schools	Grand Rapids	Mary Elderkin	P
Lawrence Technological University	Southfield	Howard Whitston	H
		Ruth Favro	P
MINNESOTA			
Bemidji State University	Bemidji	Colleen G. Livingston	H
MISSOURI			
University of Missouri-Rolla	Rolla	Mohamed Ben Rhouma	M
MONTANA			
Carroll College	Helena	Holly S. Zullo	H
		Mark R. Parker	O, H

INSTITUTION	CITY	ADVISOR	I
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NEW JERSEY			
Rowan University	Glassboro	Hieu D. Nguyen	P
NEW YORK			
Concordia College	Bronxville	John Loase	H, H
Nazareth College	Rochester	Nelson G. Rich	P
Saint Bonaventure College	Olean	Albert G. White	P
U.S. Military Academy	West Point	Christopher M. Farrell	M
		Elizabeth W. Schott	M
		Michael J. Johnson	O
NORTH CAROLINA			
Appalachian State University	Boone	Eric S. Marland	H
Elon University	Elon	Crista Coles	M, P
N.C. School of Science and Mathematics	Durham	Dot Doyle	P
Wake Forest University	Winston-Salem	Bob Plemmons	O
		Edward E. Allen	P
		Hugh N. Howards	M
OHIO			
Ohio Wesleyan University	Delaware	Richard S. Linder	H
Youngstown State University	Youngstown	J.D. Faires	H, P
		Michael Crescimanno	P
OREGON			
Eastern Oregon University	La Grande	Jeffrey N. Woodford	H
Lewis and Clark College	Portland	Thomas Olsen	H
PENNSYLVANIA			
Lafayette College	Easton	Thomas Hill	H
TEXAS			
Brazoswood High School	Clute	Deborah E. Sitka	P
Trinity University	San Antonio	Allen G. Holder	M
UTAH			
University of Utah	Salt Lake	Don H. Tucker	H
VIRGINIA			
Maggie Walker Governor's School	Richmond	Martha A. Hicks	M, H
University of Virginia	Charlottesville	Julian Victor Noble	M
WASHINGTON			
Washington State University	Pullman	V.S. Manoranjan	P
WISCONSIN			
Beloit College	Beloit	Paul J. Campbell	P

INSTITUTION	CITY	ADVISOR	I
CHINA			
Anhui University	Hefei	Haixian Wang	P
BeiHang University	Beijing	Peng Linping	H
Beijing Institute of Technology	Beijing	Cui Xiao Di	H
		Li Bing Zhao	H
		Zhang Bao Xue	P
Beijing Northern Jiaotong University	Beijing	Liu Yingdong	M
Beijing University of Chemical Technology	Beijing	Liu Damin	H
		Huang Jinyang	H
		Xu Lanxi	P
Beijing University of Posts and Tel.	Beijing	Sun Hongxiang	M
		Luo Shoushan	H
		He Zuguo	H
Central South University	Changsha	Chen Xiaosong	P
		Qin Xuanyun	H
China University of Mining and Technology	Xuzhou	Xue Xiuqian	H
		Zhu Kaiyong	P
Chongqing University	Chongqing	He Renbin	H
		Li Zhiliang	H
		Yang Xiaofan Yang	M
Dalian University	Dalian	Gang Jiatai	P
Dalian Univ. of Tech.	Dalian	Zhao Lizhong	H
		Yu Hongquan	H
		Yi Wang	H
Dong Hua University	Shanghai	Ying Mingyou	P
East China University of Sci. and Tech.	Shanghai	Ni Zhongxin	P, P
Fudan University	Shanghai	Yuan Cao	H
		Cai Zhijie	P
Hangzhou University of Commerce	Hangzhou	Hua Jiukun	H
		Zhu Ling	H, H
Harbin Engineering University	Harbin	Yu Tao	H
		Luo Yuesheng	P, P
Harbin Institute of Technology	Harbin	Hong Ge	P
		Kean Liu	M
		Tong Zheng	P
Harbin University of Sci. and Tech.	Harbin	Chen Dongyan	H
Hefei University of Technology	Hefei	Su Huaming	P
		Du Xueqiao	P
Institution of Math., Nankai Univ.	Tianjin	Lei Fu	P. P
Jiao Tong University	Shanghai	Liuqing Xiao	P
Jilin University	Changchun	Cao Chunling	P
		Wang Shuyun	P
Jinan University	Guangzhou	Hu Daiqiang	M
		Fan Suohai	P

INSTITUTION	CITY	ADVISOR	I
Nanjing Univ. of Sci. & Tech.	Nanjing	Chen Peixin	P
		Xu Chungen	H
Northern Jiaotong University	Beijing	Gui Wenhao	P
		Wang Xiaoxia	P
Northwestern Polytechnical University	Xián	Lu Quanyi	H
		Xiao Hua Yong	H
		Zhao Xuanmmin	P
Peking University	Beijing	Zhi Li	P
Peking University, School of Math & Sci.	Beijing	Liu Yulong	M, H
Shanghai Jiaotong University	Shanghai	Gang Zhou	H, P
South China University of Technology	Guangzhou	Qin Yongan	H
		Hao Zhifeng	P
		Tao Zhisui	H
Southeast University	Nanjing	Zhang Leihong	P
		Sun Zhizhong	H, P
Tianjin University	Tianjin	Liu Zeyi	H
		Song Zhanjie	H
Tsinghua University	Beijing	Huang Hongxuan	P
		Xi Deng	H
		Zhe Zhou	H
University of Electronic Sci. & Tech.	Chengdu	Xu Quanzi	H
		Yong Zhang	H, P
University of Sci. & Tech. of China	Hefei	Chao Meng	H
		Hong Zhang	M
Wuhan University of Technology	Wuhan	HuangZhangcan	P
		Peng Sijun	P
		Wang Weihua	H
Zhejiang University	Hangzhou	Yang Qifan	P
		Yong He	M
		Tan Zhiyi	H
Zhongshan University	Guangzhou	Li Caiwei	P
Zhongshan (Sun Yat-sen) University	Guangzhou	Yun Bao	H
FINLAND			
Päivölä College	Tarttila	Anne Kouhia	P, P
INDONESIA			
Institut Teknologi Bandung	Bandung	Edy Soewono	H, P
		Sapto Wahyu Indratno	P
IRELAND			
University College Dublin	Belfield	Rachel Quinlan	M
		Rachel Quinlan	P
	Dublin	Peter N. Duffy	P

INSTITUTION	CITY	ADVISOR	I
UNITED KINGDOM			
Dulwich College	London	Jeremy Lord	H

Editor's Note

For team advisors from China, we have endeavored to list family name first.