

DIMACS Center  
Rutgers University

**A Decision Logic Approach to the Port of Entry Inspection Problem**

**Annual Report**

June 2007

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## **Partner Organizations**

Telcordia Technologies: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

AT&T Labs - Research: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

NEC Laboratories America: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Lucent Technologies, Bell Labs: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Princeton University: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Avaya Labs: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

HP Labs: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

IBM Research: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Microsoft Research: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Los Alamos National Laboratory: Collaborative Research; Personnel Exchanges

Individuals from the organization participated in the program planning and research.

## Activities

Finding ways to intercept illicit nuclear materials and weapons destined for the U.S. via the maritime transportation system is an exceedingly difficult task. Until recently, only about 2% of ships entering U.S. ports have had their cargoes inspected. The percentage at some ports has now risen to 6%, but this is still a very small percentage. The purpose of this project is to develop decision support algorithms that will help to optimally intercept illicit materials and weapons. The algorithms developed have found inspection schemes that minimize total cost, including the cost of false positives and false negatives.

We envision a stream of entities arriving at a port and a decision maker having to decide how to inspect them, which to subject to further inspection and which to pass through with only minimal levels of inspection. This is a complex sequential decision making problem. Sequential decision making is an old subject, but one that has become increasingly important with the need for new models and algorithms as the traditional methods for making decisions sequentially do not scale.

Existing algorithms for optimally intercepting illicit cargo assume that sensor performance, operating characteristics of ports, and overall threat level are all fixed. The approach in this project involves decision logics and is built around problem formulations that lead to the need for combinatorial optimization algorithms as well as methods from the theory of Boolean functions, queuing theory, and machine learning. Practical complications of any such approach involve economic impacts of surveillance activities, errors and inconsistencies in available data on shipping and import terminal facilities, and the tradeoffs between combinations of sensors. A full-blown approach to the port-of-entry inspection problem includes the decision problem of when to initiate different levels of inspection if there are seasonal variations in cargo flows and cargo types, sensor reliability effects, and changing threat levels. In general terms, it is necessary to explore new sensor deployment methods and sensor configurations, the problem of false alarms from naturally occurring radiation sources (which vary spatially) and from innocent cargos (such as medical waste), and models of “information sensors.” Moreover, existing algorithms for designing port-of-entry inspection are rapidly coming up against the combinatorial explosion caused by the many possible alternative inspection strategies. In this project, we are attempting to develop an approach that brings into the analysis many of these complications.

The project is being carried out in collaboration between a university team of faculty and students and a team from the Los Alamos National Laboratory. The university team is based at DIMACS and reflects the multi-disciplinary nature of the port-of-entry inspection problem with faculty and students from Mathematics, Operations Research (RUTCOR), Computer Science, Statistics, as well as Industrial and Systems Engineering, Civil & Environment Engineering, School of Communication, Information & Library Studies, Management Science & Information Systems, among others.

The project team has reviewed in depth the initial approach to the port-of-entry inspection problem taken by the Los Alamos team. Our Los Alamos partners studied four tests for deciding if a cargo was positive, that is, contained illicit material. These tests (we will call them all sensors) were evaluation of ships manifests, passive radiation signature, radiographic image, and

induced fission. All of these have costs associated with them, including the cost of a reading indicating illicit material when there is none, a false positive (FP), the cost of a reading indicating there is no illicit material when there is, a false negative (FN), time costs of using the sensor, delay costs of waiting for the sensor, and fixed cost of equipment, labor, etc. For each sensor the readings for cargo containing illicit material (positives) and readings for cargo not containing illicit material (negatives) are random variables. It is assumed that each is distributed normally and that the mean and standard deviation for each of these distributions is known. Setting a threshold level for when a reading is considered positive controls the performance characteristics of each sensor, that is the probability of FP and the probability of FN. For example, a false positive occurs when a reading from a sensor for a cargo that does not contain illicit material falls in the range where that sensor gives a positive reading. The model our Los Alamos partners created assigned an output of 0 (absence of illicit material) or 1 (presence of illicit material) for each sensor. In general,  $n$  sensors will yield a string (vector) of 0's and 1's of length  $n$ . A decision function is a Boolean function  $F$  on an  $n$ -dimensional vector with output 0 (negative) indicating the cargo is not suspected of containing illicit material and an output of 1 (positive) indicating the cargo is suspected and must be "unstuffed." The cost of a false positive is the cost of unstuffing, \$600. The cost of a false negative was based on the estimated cost of the destruction of the World Trade Center, \$50 billion, times the estimated fraction of imports with weapons of mass destruction (WMD), 1 per 5 years. To which sensor a cargo is sent depends on the output of the previous sensor. This can be modeled with a binary decision tree (BDT). The best LANL could accomplish was to find the binary decision tree in the case of 4 sensors that would minimize total cost. Restricting to complete (every variable is required) and monotone (if  $F(0,1,1,0)$  is 1 then  $F(1,1,1,0)$  must also be 1) Boolean functions, there are 114 possible functions and 11,808 possible binary decision trees. Using two months data from the LA Long Beach port, by exhaustive search it was determined that there was 1 best, the best 100 fell into 10 patterns, and there were about 300 that were close enough to optimal.

In reality, we will want to use many more sensors and the large number of possible trees makes an exhaustive search infeasible. One goal of this project is to understand the characteristics and behaviors of the solution space with the objective of developing heuristics that will allow rapid computation in finding optimal and near optimal trees. This heuristic will need to be able to scale up to 12, 20, or even higher numbers of sensors.

Several problems were recognized with this model. There are many different types of costs involved. There are fixed costs and salary costs for the inspection stations. There are delay costs that are primarily borne by the shippers. Also, a sufficiently long delay could cause the entire system to collapse causing proliferating economic costs throughout the country and the world. The delays can be a random variable; for example there is variability in the time to read the radiograph.

The Rutgers team has subdivided their approach into four interdependent parts. One group is studying the sensitivity of the determination of optimal and near optimal trees to the input parameters. As input parameters such as the costs of false positives and false negatives, the costs of delays, etc., are estimated with more or less accuracy, one wants solutions whose sensitivity to changes in these parameters is known and tolerable. This group is also applying data mining techniques to study the dataset of 11,808 possible binary decision trees provided by LANL for

the case of 4 sensors. A second group is considering the optimization problem in the context of a shipping port and building a simulation model of inspection stations as one part of an operating port. Such a model will allow the estimation of some of the cost parameters by, for example, providing estimates of delays. A third group is developing new modeling approaches that are computationally cheap, highly scalable, and able to incorporate various cost factors with enough flexibility to include future technologies. A fourth group is investigating the optimum threshold levels for sensors so as to minimize overall cost as well as minimize the probability of not detecting hazardous material.

This NSF grant builds on the research of a previous ONR grant, “DIMACS Project on Algorithms for Port of Entry Inspection” (N00014-05-1-0237), which ended on January 31, 2007, a current ONR grant on “Optimization Problems for Detection Systems” (N00014-07-1-0299), and an award from Rutgers University through its Academic Excellence program. The results described here are the product of ONR, NSF, and Rutgers funding, which we have combined in support of this effort.

## **Findings**

### *Sequential decision making algorithms for port of entry inspection: overcoming computational challenges*

As a stream of containers arrives at a port, a decision maker has to decide how to inspect them, which to subject to further inspection, which to pass through with only minimal levels of inspection, etc. Stroud and Saeger looked at this as a sequential decision making problem and formulated it, in an important special case, as a problem of finding an optimal binary decision tree for an appropriate binary decision function. In earlier work in this project, Anand et al reported on experimental analysis of the Stroud-Saeger method that led to the conclusion that the optimal inspection strategy is remarkably insensitive to variations in the parameters needed to apply the method.

Project participants David Madigan, Sushil Mittal, and Fred Roberts built on the above work by formulating the port-of-entry inspection sequencing task as a problem of finding an optimal binary decision tree for an appropriate Boolean decision function. They found new algorithms that are more computationally efficient than those presented by prior researchers mentioned. They achieved these efficiencies through a combination of specific numerical methods for finding optimal thresholds for sensor functions and a novel binary decision tree search algorithm that operates on a space of potentially acceptable binary decision trees. It is known that the number of binary decision trees corresponding to complete, monotone Boolean functions increases exponentially with addition of each new sensor. Expanding the space of trees in which to search for a cost-minimizing tree to the space of complete monotonic trees (CM tree space) turned out to be beneficial. Although finding a cost-minimizing tree in CM tree space presents a significant computational challenge as the number of sensors increases, Madigan, Mittal and Roberts were able to address this challenge via heuristic search strategies that build on notions of neighborhoods. Furthermore, while CM tree space includes all the trees arising from complete, monotonic Boolean functions, it includes some trees that do not arise from complete and

monotonic Boolean functions, but still correspond to viable and potentially useful inspection strategies. A paper describing these results and methods is cited below.

*Proof of cost-minimizing tree space irreducibility for  $n > 2$*

Sushil Mittal proved irreducibility of the sequential decision making algorithm developed by Madigan, Mittal, and Roberts. The Madigan, Mittal, and Roberts algorithm modified methods to traverse the tree space by Chipman et al to define a notion of neighborhood that better suits the port-of-entry inspection problem. Basically, they defined four kinds of operations on a tree to get its neighboring trees and defined something called a “simple tree.” A simple tree is a complete and monotonic decision tree in which every sensor occurs exactly once in such a way that there is exactly one path in the resultant tree with all sensors in it. Mittal proved that any simple tree can be reached from any other simple tree, using neighborhood operations repeatedly in  $\tau_n$ , where  $\tau_n$  represent the entire space of cost-minimizing trees in  $n$  sensors. After proving this, the task that remained was to prove that a simple tree can be reached from any arbitrary tree and any arbitrary tree from a simple tree. To prove this he made frequent use of an algorithm called smartMerge. A paper describing the proof is under development.

*Deceptive detection methods for optimal security with inadequate budgets: the screening power index*

Paul Kantor and Endre Boros developed game theoretic strategies for selecting the best methods for screening containers at a nation’s ports. Their methods can lead to substantial increases in the detection of nuclear contraband, at no increase in costs.

Detection of contraband depends on countermeasures, some of which involve examining cargo containers and/or their associated documents. Documents screening is the least expensive, physical methods such as gamma ray detection are more expensive, and definitive manual unpacking is most expensive. It is not possible to apply the full array of methods to all incoming cargoes, for budgetary reasons. Kantor and Boros studied the problem using principles of game theory. Their method maximizes detection rate. Furthermore, opponents cannot predict what tests will be applied to the containers. This yields increases of as much as 100% in detection, with essentially no increase in inspection cost.

Remarkably, they found that the cost-effectiveness of any particular screening test may be summarized by a single number, the Screening Power Index (SPI). This index depends on the sensitivity and specificity (or operating characteristics) of the test, on known cost information, and on estimated probabilities. These numbers are, in reality, difficult to find, or closely held. However, once they are determined, it is easy to compute the index. The method can therefore be applied by operators of terminals and sensitive information need not be shared with researchers. The SPI applies precisely when budget limitations dictate that not all containers can be screened. In this situation randomization strategies will improve the detection rate. Such an approach, in the terminology of game theory, is called a mixed strategy. In addition to its optimality properties, it has the virtue of deception, as properly implemented it thwarts an opponent’s efforts to circumvent it. A paper describing the Kantor-Boros results is cited below.

### *Port-of-entry inspection: sensor deployment policy optimization*

Project participants Elsayed Elsayed, Christina Schroepfer, Minge Xie, Hao Zhang, Yada Zhu, and Mingyu Li also considered the problem of container inspection through a specific sequence of inspections to detect the presence of nuclear materials, biological and chemical agents, and other illegal shipments. The threshold levels of sensors at the inspection stations affect the probabilities of incorrectly accepting or rejecting a container. Elsayed, et al. developed several optimization approaches on how to select sensor threshold levels under considerations of misclassification errors, total cost of inspection, and budget constraint. They gave examples of the use of their approach in different sensor arrangements. A paper describing the results is cited below.

### *Risk Minimization for Vessel Traffic at Marine Ports*

Marine ports such as the Philadelphia port and the New York/New Jersey port complex service a large number of vessels carrying Liquefied Natural Gas (LNG), Liquefied Petroleum Gas (LPG) and oil. Such cargo poses high safety and security risks due to their explosive nature which could make them the target of terrorists.

Marine ports are often situated on waterways connecting various commercial loading/unloading terminals. In the case of Philadelphia, the waterway is more than 100 miles long. Traffic through the waterway is subject to considerable collision risk. The maximum risk involved anywhere along a waterway depends on operating decisions, such as the minimal proximity of vessels and the scheduling of arriving and departing vessels.

Benjamin Melamed and colleagues have performed a risk assessment of the waterway zones, as measured by risk factors to vessels and the surrounding banks. The latter depends on population density in a zone and the value of facilities on its banks. Zones should be small enough to capture major changes in risk factors among adjacent zones.

The key challenge in this research was to express the total risk of a given zone and, in particular, of each bank in a zone, as a function of the risk factors of all the components involved. Their approach was a combination of simulation and optimization. Vessel traffic was simulated to drive the computation of risk factors. An optimization algorithm to determine the best inter-arrival and inter-departure intervals that mitigate or minimize the maximal risk across waterway zones is under development.

### **Outreach Activities**

Faculty participants in this project are serving as mentors in the DIMACS Research Experience for Undergraduates (REU) program, introducing undergraduates to some of the research issues and problems involved in port security and generating interest in homeland security problems among the next generation of researchers. Specifically, project participants Elsayed A. Elsayed and Minge Xie are mentoring an REU student this summer (2007) working on “Optimization of sequencing and threshold levels of detection systems.” The student, Tsvetan Asamov from Kenyon College, is investigating approaches for determining the optimum arrangements of



sensors and their corresponding threshold levels while considering potential measurement errors and cost and other constraints. He will also look at efficient approaches for investigating inspection systems with a large number of sensors. Finally, he will use the theory to write practical algorithms. More details on this and other REU projects are available at <http://dimacs.rutgers.edu/REU/2007/proposed.html>. The student has prepared a website on his progress located at <http://dimax.rutgers.edu/~asamovt/>.

“Algorithms for port-of-entry inspection” was one of the topics presented to high school teachers in a DIMACS workshop on the Mathematics of Homeland Security held in May 2007. The workshop was designed to help participating teachers introduce homeland security topics to their high school students. Project participant Fred Roberts spoke on inspecting containers at ports. He started with a discussion of bit strings and boolean functions and described how the container inspection problem can be viewed as the sequential decision making problem. Roughly twenty high school teachers responsible for teaching Discrete Math, Statistics, Computer Science and Algebra I and II participated in this program.

In May 2007, Rutgers hosted the Fifth IEEE International Conference on Intelligence and Security Informatics. Project PI, Fred Roberts, and project participant, Paul Kantor, served as conference co-chairs. Security informatics is a rapidly growing multidisciplinary area that crosscuts numerous disciplines, including computer science, information technology, engineering, public policy, medicine (medical informatics), biology (bioinformatics), social and behavioral sciences, political science, and modeling and analysis. The combination of intelligence and security informatics strives to integrate computational social science, advanced information technologies and algorithms to support counterterrorism and homeland security policies, organizations and operations (both domestically and internationally). The conference provided a forum for discussions among academic researchers (in information technologies, computer science, public policy, and social studies), local, state, and federal law enforcement and intelligence experts, as well as information technology industry consultants and practitioners. Because of our location near major New York and New Jersey ports, port security was made a key conference theme. The conference featured parallel sessions on port security and infrastructure protection as well as an opening plenary panel featuring practitioners with port security responsibility from institutions that include the Coast Guard, the Port Authority of NY/NJ, Moran Shipping Agency, and the FBI.

## Books

E. Boros, E. A. Elsayed, P. Kantor, F. Roberts and M. Xie, “Optimization problems for port-of-entry detection systems,” in *Intelligence and Security Informatics: Techniques and Applications*, edited by Hsinchun Chen and Chris Yang, Springer 2007

E. A. Elsayed and H. Zhang, “Design of optimum simple step-stress accelerated life testing plans,” to appear in *Recent Advancement of Stochastic Operations Research*, edited by S. Osaki, T. Dohi and K. Sawaki, World Scientific, Singapore, forthcoming 2007.

E. A. Elsayed and H. Zhang, "Optimum threshold level of degrading systems based on sensors observation," *Recent Advances in Reliability and Quality in Design*, edited by Hoang Pham, Springer Series in Reliability Engineering, 2007.

## Papers

T. Altiok and B. Melamed, "Modeling of the container inspection process at marine ports," in preparation.

T. Altiok and D. Jagerman, "Modeling vessel arrivals in marine ports," in preparation.

E. Boros, L. Fedzhora, P. Kantor, K. Saeger, and P. Stroud, "Large scale linear programming model for finding optimal container inspection strategies," in preparation.

E. A. Elsayed, M. Li, M. Xie, M., H. Zhang, Y. Zhu, and C. Young, "Inspection policy optimization in port-of-entry systems," *Proceedings Fifteenth Industrial Engineering Research Conference*, Nashville, Tennessee, May 19-23, 2007.

E. A. Elsayed, C. Schroepfer, M. Xie, H. Zhang, Y. Zhu, and M. Li, "Port-of-entry inspection: sensor deployment policy optimization," submitted to *IEEE Transactions* (under revision).

P. Kantor and E. Boros, "Deceptive detection methods for optimal security with inadequate budgets: the screening power index," submitted to *Science Magazine*.

D. Madigan, S. Mittal, and F. Roberts, "Sequential decision making algorithms for port-of-entry inspection: overcoming computational challenges," to appear in *Proceedings of the IEEE International Conference on Intelligence and Security Informatics*, 2007.

H. Zhang, C. Schroepfer, and E. A. Elsayed, "Sensors threshold in port-of-entry inspection systems," *Proceedings of the 12th ISSAT International Conference on Reliability and Quality in Design*, Chicago, Illinois, USA, August 3-5, 2006, pages 172-176.

## Talks

T. Altiok, "Port security and logistics," National University of Singapore, March 20, 2007.

T. Altiok, "Findings and observations in the trip to Hong Kong and Singapore," Area Maritime Security Committee of Sector Delaware, Philadelphia, April 4, 2007.

E. Boros, "Large Scale Linear Programming Applications," *EURO 2006 Meeting*, Reykjavik, Iceland, July 2-5, 2006.

E. Boros, "Optimization models for container inspection," *Seventh New Jersey Universities Homeland Security Research Consortium Symposium*, November, 2006.

E. Boros, L. Fedzhora, P. Kantor, K. Saeger, and P. Stroud, "Large Scale Optimization Model for Optimizing Container Inspection," Third Conference on Mathematical Methods in Counterterrorism, with a special focus on order theory and reflexive theory, Washington, D.C. September 28-30, 2006 (invited).

E. A. Elsayed, M. Li, M. Xie, H. Zhang, Y. Zhu, and C. Young, "Inspection policy optimization in port-of-entry systems," *Fifteenth Industrial Engineering Research Conference*, Nashville, Tennessee, May 19-23, 2007..

R. Hoshino, "Improving the risk-scoring algorithm of marine cargo containers," DIMACS Seminar, Piscataway, NJ, Nov 13-14.

F. Roberts, "Social Choice and Computer Science," *EURO 2006 Meeting*, Reykjavik, Iceland, July 2-5, 2006 (invited semi-plenary session).

F. Roberts, "Algorithms for Port of Entry Inspection for WMDs," Workshop on mathematics and homeland security, Piscataway, NJ, May 2007.

D. Madigan, S. Mittal, and F. Roberts, "Sequential decision making algorithms for port-of-entry inspection: overcoming computational challenges," *IEEE International Conference on Intelligence and Security Informatics*, New Brunswick, 2007.

H. Zhang, C. Schroepfer, E. A. Elsayed, and F. Roberts, "Optimum thresholds of sensors for container inspection systems," Third Conference on Mathematical Methods in Counterterrorism, with a special focus on order theory and reflexive theory, Washington, D.C. September 28-30, 2006 (invited).

H. Zhang, C. Schroepfer, and E. A. Elsayed, "Sensors threshold in port-of-entry inspection systems," 12th ISSAT International Conference on Reliability and Quality in Design, Chicago, Illinois, August 3-5, 2006.

### **Main website**

<http://dimacs.rutgers.edu/Workshops/PortofEntry/>

### **Other Specific Products**

[http://dimacs.rutgers.edu/port\\_security\\_lab/](http://dimacs.rutgers.edu/port_security_lab/)

The DIMACS-CAIT Laboratory for Port Security (LPS) at Rutgers was established in 2006 to coordinate, foster and carry out collaborative research on marine/land port security, as well as the security of approach roads, including bridges and tunnels, and the coastal waters that surround them. LPS addresses key issues relevant to marine/land port and bridge/tunnel security operations, coastal interdiction, preparedness and recovery from high-consequence events at ports and the surrounding transportation infrastructure. The LPS research scope also includes analysis of technological approaches, as well as modeling and evaluation of field operations.

## **Software**

A prototype simulation model of cargo security operations in a container port including handling, storage and inspection has been developed using the ANYLOGIC simulation tool that is web-based.

## **Contributions**

### **Contributions within Discipline**

The mathematics behind port-of-entry problems is inherently multidisciplinary. The DIMACS team consists of faculty and students from mathematics, computer science, statistics, operations research, electrical and computer engineering, industrial and systems engineering, information and library studies, and management science and information systems. Students are mentored by teams of faculty with different specializations. For example, mathematics REU student Tsvetan Asamov from Kenyon College is mentored by Elsayed A. Elsayed from Industrial and Systems Engineering and Minge Xie from Statistics.

Another example is the involvement of Sushil Mittal, a graduate student in Electrical and Computer Engineering, with faculty from Statistics (David Madigan) and Mathematics (Fred Roberts) in proving irreducibility of their search algorithm.

The work of this project relates closely to critical issues of risk assessment in homeland security. This has led to work on risk assessment for critical infrastructure other than ports in collaboration with the New Jersey office of Homeland Security and Preparedness.

### **Contributions to Other Disciplines**

The research outcomes from this project are also applicable to other modern problems. For example, the work of Liliya Fedzhora (graduate student), Paul Kantor, and Endre Boros from Rutgers, and Phil Stroud and Kevin Saeger from Los Alamos on optimal inspection strategies for container inspection can be generalized to a methodology for other practical problems, such as call-center scheduling and hardware/network diagnosis problems. The methods we are working on also have application to sequential decision making problems in making medical diagnosis, circuit complexity in computer science, reliability of computer and communication networks, etc.

### **Contributions Beyond Science and Engineering**

This project was motivated by the vitally important problem of screening the materials that enter our country through our ports for dangerous and destructive materials. It is a classic example of how real-world problems motivate and direct the development of fundamental research.

One of the outcomes of this project has been the development of a Laboratory for Port Security (LPS) at Rutgers. LPS was established by a Rutgers University Academic Excellence Fund grant to carry out collaborative research on marine/land port security, as well as the security of surrounding transportation infrastructure and coastal waters. LPS addresses key issues relevant to marine/land container inspection operations and technology, bridge/tunnel security operations, coastal interdiction, and preparedness for and recovery from high-consequence events. The LPS research scope includes the analysis of relevant technological approaches (wireless networks, RFID, image processing, HF radar) and modeling and evaluation of field operations and risk (mathematical and simulation). Through LPS project participants have become heavily involved with Department of Homeland Security Customs and Border Protection, the US Coast Guard, and the New Jersey Office of Homeland Security and Preparedness, (OHSP), and in particular in helping develop port security training materials. Participants are also involved with the Port Authority of New York/New Jersey and with several private marine terminal operators.

Project participant Tayfur Altiok is serving as a member of the Area Maritime Security Committee's Training and Exercise Subcommittee. This is the committee that determines risks and vulnerabilities in New York and Philadelphia. He sent a proposal to the New Jersey Department of Transportation for risk analysis of the vessel traffic in the Delaware River and Bay (Port Philadelphia) in January and another one to the Department of Homeland Security to place sonars in the New York harbor for underwater surveillance in February. He also organized a seminar given by Beth Ann Rooney, Manager of Port Security, Port Authority of NY/NJ on Feb 20, 2007. Additionally, he visited the ports of Los Angeles, HIT in Hong Kong, and PSA in Singapore to study port security and logistics issues in these mega ports. In March 2007 he initiated collaborations with universities including the Hong Kong University of Science and Technology and the National University of Singapore.

DIMACS hosted a November 13-14, 2006 visit by Richard Hoshino of the *Canada Border Services Agency* (CBSA) in which he delivered a talk on mathematical techniques that the CBSA applies in container inspection, and subsequent discussions identified numerous areas for future interaction. Hoshino has since made a proposal to his management for them to adopt some of our methods in their container security inspection protocols and to provide us with data so that we can collaborate further.

Project members have had a variety of interactions with agencies responsible for port security. The project team visited the Port of Elizabeth, New Jersey on December 6, 2006, and was escorted by a Customs and Border Protection team for a behind-the-scenes visit to the container terminal. This included visits to the Maher and Port Newark Container Terminals and a first-hand view of the mobile VACIS machines that are used to test cargo for contraband and weapons. Project members are in the process of developing joint projects with the Coast Guard Delaware Bay Sector as well as with the New Jersey Office of Homeland Security and Preparedness.

### **Contributions to Human Resources Development**

Many graduate students have been heavily involved in this project right from the beginning. This involvement is informing their research and determining the direction of their future careers. In

the academic year 2006 – 2007 Abdullah Karaman, Christina Schroepfer, Yada Zhu, and Mingyu Li have been working with Dr. Elsayed, Ozgecan Uluscu with Dr. Altiok, Sushil Mittal with Drs. Madigan and Roberts, Liliya Fedzhora with Dr. Boros, and Saket Anand with Dr. Mammone.

Graduate students are playing a major role in the results of the team's research. For example, Sushil Mittal made a significant contribution to the sequential decision making algorithm developed by Madigan, Mittal, and Roberts and then proved its irreducibility. Christina Schroepfer, Hao Zhang, and Mingyu Li have been working with Dr. Elsayed. They have been considering the problem of container inspection through a specific sequence of inspections to detect the presence of nuclear materials, biological and chemical agents, and other illegal shipments.

In May 2007 Fred Roberts presented a workshop on "Algorithms for port-of-entry inspection" to high school teachers interested in the mathematics of homeland security. The workshop was designed to help participating teachers introduce homeland security topics to their high school students, thereby training students in this type of mathematics early in their careers.

In the summer of 2007 Drs. Elsayed and Xie are mentoring an REU student working on "Optimization of sequencing and threshold levels of detection systems." The student, Tsvetan Asamov from Kenyon College, is investigating approaches for determining the optimum arrangements of sensors and their corresponding threshold levels while considering potential measurement errors and cost and other constraints.