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Judge's Commentary: The Outstanding Elephant Population Papers

Gary Krahn
Department of Mathematics
U.S. Military Academy
West Point, NY
ag2609@exmail.usma.army.mil

Introduction

The judges were very impressed by the breadth of insight revealed by the "modelers" in this the second year of the ICM Contest. Each of the six required tasks in the problem were individually weighted; however, papers were ultimately evaluated on their overall effectiveness to formulate a policy that would solve the overpopulation problem and create a healthy environment for a herd of 11,000 elephants.

The Problem

At first glance, the information and data provided in the problem statement appear to be sufficient to construct a model to capture the population growth of the elephants under specific control measures. This problem, however, was not clear-cut. As the contestants formulated and refined their assumptions, they confronted the complexities typically associated with an open-ended problem. The initial task was to develop and use a model to investigate how the contraceptive dart might be used for population control. The modelers, however, do not know the initial age structure. Nor are they privy to the implementation procedures of culling, relocation, darting, and the cultural issues surrounding population control.

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The Science

Papers were evaluated based on an understanding and application of science, model development, and analysis. Knowledge of the elephant's life-cycle and survival characteristics was important in the design of an appropriate solution to this problem. Environmental science provided the modelers with the foundation to make "realistic" and appropriate assumptions. More important, it gave teams confidence in the data provided and in the results of their models. In essence, understanding the science of the biological and environmental data transformed this problem into a real-world application. Many teams, through research, verified that after 5 years of age, elephants live in relative safety—there is a low rate of terminal diseases, accidents are rare, and there are few natural predators. In addition, they discovered that deaths of elephants often occurs after 60 years of age because of eating complications. Teams that gained an understanding of biological issues affecting elephants also achieved better "control" of the information in the problem statement. As a result, the top interdisciplinary teams were able to find insights into the significant parameters that influenced the elephant population growth.

The Model

Some teams constructed an analytic model, some used population models found in the literature, and others developed simulations to replicate the real world behavior. All teams used some simplifying assumptions to reduce the scope of the problem. The judges thought it was important to keep the assumptions reasonable and to avoid making unnecessary assumptions. Several teams examined (or constructed) different population models simultaneously to verify their work and to gain perspectives on how to adapt established modeling techniques for this particular problem. A few teams effectively simplified the problem by modeling only the female population. More than a few teams used several solution techniques (the Leslie matrix and a simulation) and compared the results. Other teams constructed models that captured the dynamics of individual elephants and compared that to models that grouped elephants into categories. The judges were heartened by the number of teams that attempted to validate the models.

In Task 4, the modelers were asked to investigate the affect of disease and uncontrolled poaching after darting. Teams that used several modeling approaches almost always discovered that the population would oscillate for several years after a dramatic population change and then would recover. Simulations were effectively used to reveal this phenomenon and graphical techniques were able to display this result very clearly.

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The Analysis

The mathematics required to explore the dynamics of the population growth did not require sophisticated methods. Difference equations, discrete dynamical systems, differential equations, transformation matrices (Leslie model), and computer simulations were applied with great success by many of the 69 teams in the contest. Some teams examined the long-term behavior of the system using the eigenvalues of the transition matrix—a very nice application of matrix algebra. The judges were delighted that the top teams discovered that their results were insensitive to assumptions about the initial age structure. Computation and calculation were not the most important features for successfully solving this problem. The reasoning process, modeling, and problem solving were of much greater importance.

Interdisciplinary

Again, the characteristic of a strong paper was the knowledge of environment science and resource management and application of valid modeling concepts, along with terminology that explained the analysis, outcomes, and recommendations. The top papers not only conducted a thorough analysis but also shared their method of reasoning in sufficient detail. The problem statement revealed that park officials were very skeptical about mathematical modeling. Therefore, it was essential to outline the modeling procedures and the implications of any assumptions. The analyst's credibility (essential for the eventual implementation of the model) could be enhanced by revealing knowledge about the elephant life-cycle, discussion of the advantages and disadvantages of models/simulations, and sharing with the park officials an appreciation of the complexity of the problem. Some National Parks in South Africa cover over 2 million acres, larger than the state of New Jersey (and no turnpike!). Counting elephants in these rugged areas is not simple—it necessitates historical evidence and statistical inference. Determining the age and sex distribution of elephants can be extremely difficult especially during periods when external forces are changing the natural equilibrium of the herds. Discussing these considerations of the ecosystem with the Park Officials was an important element of Task 5—increasing the confidence of park managers. A team's lack of appreciation for the complex environment was often revealed in the manner in which the darting would be implemented. Some teams suggested counting elephants every year and only darting elephant of specific age groups—probably an impossible undertaking. Other teams realized that it would be impossible to "tag" darted elephants and suggested darting every two years to help eliminate the problem of darting the same elephant several times in a given year.

The interplay between darting and relocation was the theme of Task 3. It was interesting how some teams believed that relocation could be done very

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easily and other teams wrestled with the cost and complications of relocating hundreds of elephants—hundreds of big, heavy, cumbersome, stubborn elephants. The understanding of resource management was a critical ingredient in solving this problem. The top teams did this very well.

Presentation

Clarity of presentation is essential to good research and analysis and it provides the ability to effectively influence the decision making process. Many teams this year presented very clear and concise support of their work. The stronger teams carefully created the appropriate mixture of words, graphs, algorithms, and analysis to present their reasoning and recommendations.

Often, the results for a specific task were spread throughout the paper and were not confined to a particular section of the paper. Over the years, however, modeling teams have continued to place a greater emphasis on the write-up. This has been a very pleasant trend to witness.

Conclusion

Almost every team felt comfortable transitioning their work to other possible scenarios. They revealed a confidence in generalizing their analysis and adapting it to specific situations.

This problem was successful because to write a top paper required an understanding of science, research, and mathematics. The best teams revealed the value of solving a problem from an interdisciplinary perspective. The top three papers are remarkable efforts to solve an open-ended problem in a very shot period of time! Congratulations to all the interdisciplinary teams and especially the three “outstanding” teams.

About the Author

Gary Krahn received his Ph.D. in Applied Mathematics at the Naval Postgraduate School. He is currently the Deputy Head of the Dept. of Mathematical Sciences at the U.S. Military Academy at West Point. His current interests are in the study of generalized de Bruijn sequences for communication and coding applications. He enjoys his role as a judge and associate director of the ICM.

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About the Problem Author

Chris Arney
Gary Krahn
Department of Mathematics
U.S. Military Academy
West Point, NY
ad6819@exmail.usma.army.mil
ag2609@exmail.usma.army.mil

In the second year of ICM, the contest directors wanted a problem involving resource management as it relates to modeling in environmental sciences. In addition, we wanted the problem to involve data analysis, to be realistic, and to be open-ended where no solution is readily available. Our search converged to the elephant problem of Professor Tony Starfield—and we believe our search was successful.

Professor Anthony M. Starfield in the Dept. of Ecology, Evolution, and Behavior, University of Minnesota, carefully guided us in composing this problem. He is an applied mathematician who enjoys using mathematics and computers to help solve "real-life" problems. Prof. Starfield has his Ph.D. from the University of the Witwatersrand, Johannesburg, and has worked on many problems in wildlife conservation, in particular, modeling of populations and ecosystems. For 20 years, he has built models to aid management decisions in the game parks of Southern Africa. His current research work is in two separate areas.

- He investigates how decisions are made in conservation biology and attempts to develop models that feed into a formal multi-objective decision process that reflects both the uncertainty inherent in conservation problems and the various interests of the players in these decisions.
- He develops new paradigms for modeling ecosystem dynamics. This approach has been applied to forest succession in Minnesota, elephant-tree dynamics in Zimbabwe, and global warming on Alaskan tundra.

Tony Starfield is also the co-author of *How to Model It: Problem-Solving for the Computer Age* and *Building Models for Conservation and Wildlife Management*.

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Our question combined two components that Prof. Starfield has incorporated into his work:

- using mathematical models effectively in ecology and conservation biology, and
- using the creative aspect of modeling as a logical and practical process.

If you compare the ICM problem with the problem that Tony Starfield has been investigating (see below), you will see that only the names have been changed to protect the innocent. As we coordinated with Tony, we found that he spends considerable time in South Africa solving important problems. Here is the problem that Tony suggested:

> The Kruger National Park in South Africa has tried to maintain a steady elephant population. Their policy is to keep the number of elephants fixed; and for the past 20 or more years they have attempted to count the total population each year, then remove whole herds to keep the population stable. This operation has involved shooting (for the most part) and occasionally relocating elephants every year. There has been a public outcry against the shooting of elephants, and it is not feasible to relocate large number of elephants. A contraceptive dart has been developed that will prevent a mature elephant cow from conceiving for a period of two years. How can darting help control the population of elephants?

Tony suggested that that overall task is to develop and use models to investigate how the contraceptive dart might be used for population control. He then crafted a series of tasks to help guide the students.

We thought it would be best not to specify the Kruger Park, to allow for greater generality. Because of the assumptions that have to be made, this is an open-ended problem. This problem was exciting because it was accessible to students with a variety of backgrounds, without losing the "real-world" application. It also required teams to do research to model the situation appropriately. A goal was to provide an opportunity to have students discover that modeling skills can allow them to make significant contributions to society. We hope that a little of Tony Starfield's commitment to our environment and modeling rubbed off on those involved with this problem.

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About the Author

Anthony Starfield received his Ph.D. at the University of Witwatersrand, Johannesburg. He is an applied mathematician who enjoys solving environmental problems. For 20 years, Tony has been working with engineers to build models to aid management decisions in the game parks of Southern Africa. What was essentially a hobby grew into a career. Today he would be described as an ecological modeler. Currently, he is a Professor in the Department of Ecology, Evolution, and Behavior at the University of Minnesota College of Biological Science. His home page is `http://biosci.cbs.umn.edu/eeb/faculty/StarfieldAnthony.html` .