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2009 MCM Problems

PROBLEM A: Designing a Traffic Circle

Many cities and communities have traffic circles—from large ones with many lanes in the circle (such as at the Arc de Triomphe in Paris and the Victory Monument in Bangkok) to small ones with one or two lanes in the circle. Some of these traffic circles position a stop sign or a yield sign on every incoming road that gives priority to traffic already in the circle; some position a yield sign in the circle at each incoming road to give priority to incoming traffic; and some position a traffic light on each incoming road (with no right turn allowed on a red light). Other designs may also be possible.

The goal of this problem is to use a model to determine how best to control traffic flow in, around, and out of a circle. State clearly the objective(s) you use in your model for making the optimal choice as well as the factors that affect this choice. Include a Technical Summary of not more than two double-spaced pages that explains to a Traffic Engineer how to use your model to help choose the appropriate flow-control method for any specific traffic circle. That is, summarize the conditions under which each type of traffic-control method should be used. When traffic lights are recommended, explain a method for determining how many seconds each light should remain green (which may vary according to the time of day and other factors). Illustrate how your model works with specific examples.

PROBLEM B: Energy and the Cell Phone

This question involves the “energy” consequences of the cell phone revolution. Cell phone usage is mushrooming, and many people are using cell phones and giving up their landline telephones. What is the consequence of this in terms of electricity use? Every cell phone comes with a battery and a recharger.

Requirement 1

Consider the current US, a country of about 300 million people. Estimate from available data the number H of households, with m members each, that in the past were serviced by landlines. Now, suppose that all the landlines are replaced by cell phones; that is, each of the m members of the household has a cell phone. Model the consequences of this change for electricity utilization in the current US, both during the transition and during the steady state. The analysis should take into account the need for charging the batteries of the cell phones, as well as the fact that cell phones do not last as long as landline phones (for example, the cell phones get lost and break).

Requirement 2

Consider a second “Pseudo US”—a country of about 300 million people with about the same economic status as the current US. However, this emerging country has neither landlines nor cell phones. What is the optimal way of providing phone service to this country from an energy perspective? Of course, cell phones have many social consequences and uses that landline phones do not allow. A discussion of the broad and hidden consequences of having only landlines, only cell phones, or a mixture of the two is welcomed.

Requirement 3

Cell phones periodically need to be recharged. However, many people always keep their recharger plugged in. Additionally, many people charge their phones every night, whether they need to be recharged or not. Model the energy costs of this wasteful practice for a Pseudo US based upon your answer to Requirement 2. Assume that the Pseudo US supplies electricity from oil. Interpret your results in terms of barrels of oil.

Requirement 4

Estimates vary on the amount of energy that is used by various recharger types (TV, DVR, computer peripherals, and so forth) when left plugged in but not charging the device. Use accurate data to model the energy wasted by the current US in terms of barrels of oil per day.

Requirement 5

Now consider population and economic growth over the next 50 years. How might a typical Pseudo US grow? For each 10 years for the next 50 years, predict the energy needs for providing phone service based upon your analysis in the first three requirements. Again, assume electricity is provided from oil. Interpret your predictions in term of barrels of oil.

2009 ICM Problem

PROBLEM C: Creating Food Systems: Re-Balancing Human-Influenced Ecosystems

To view and print **problem C**, you will need to have the Adobe Acrobat Reader installed in your Web browser. Downloading and installing Acrobat is simple, safe, and only takes a few minutes.

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**[Click the Title Below To View a PDF of Problem C
Creating Food Systems: Re-Balancing Human-Influenced Ecosystems](#)**

COMAP Mirror Site: For more in:

<http://www.comap.com/undergraduate/contests/mcm/>

MCM: The Mathematical Contest in Modeling
ICM: The Interdisciplinary Contest in Modeling

2007 Contest Problems

MCM PROBLEMS

PROBLEM A: Gerrymandering

Gerrymandering The United States Constitution provides that the House of Representatives shall be composed of some number (currently 435) of individuals who are elected from each state in proportion to the state's population relative to that of the country as a whole. While this provides a way of determining how many representatives each state will have, it says nothing about how the district represented by a particular representative shall be determined geographically. This oversight has led to egregious (at least some people think so, usually not the incumbent) district shapes that look "unnatural" by some standards.

Hence the following question: Suppose you were given the opportunity to draw congressional districts for a state. How would you do so as a purely "baseline" exercise to create the "simplest" shapes for all the districts in a state? The rules include only that each district in the state must contain the same population. The definition of "simple" is up to you; but you need to make a convincing argument to voters in the state that your solution is fair. As an application of your method, draw geographically simple congressional districts for the state of New York.

PROBLEM B: The Airplane Seating Problem

Airlines are free to seat passengers waiting to board an aircraft in any order whatsoever. It has become customary to seat passengers with special needs first, followed by first-class passengers (who sit at the front of the plane). Then coach and business-class passengers are seated by groups of rows, beginning with the row at the back of the plane and proceeding forward.

Apart from consideration of the passengers' wait time, from the airline's point of view, time is money, and boarding time is best minimized. The plane makes money for the airline only when it is in motion, and long boarding times limit the number of trips that a plane can make in a day.

The development of larger planes, such as the Airbus A380 (800 passengers), accentuate the problem of minimizing boarding (and deboarding) time.

Devise and compare procedures for boarding and deboarding planes with varying numbers of passengers: small (85–21), midsize (210–330), and large (450–800).

Prepare an executive summary, not to exceed two single-spaced pages, in which you set out your conclusions to an audience of airline executives, gate agents, and flight crews.

An article appeared in the NY Times Nov 14, 2006 addressing procedures currently being followed and the importance to the airline of finding better solutions. The article can be seen at:
<http://travel2.nytimes.com/2006/11/14/business/14boarding.html>



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MCM: The Mathematical Contest in Modeling

2003 MCM Problems

PROBLEM A: The Stunt Person

An exciting action scene in a movie is going to be filmed, and you are the stunt coordinator! A stunt person on a motorcycle will jump over an elephant and land in a pile of cardboard boxes to cushion their fall. You need to protect the stunt person, and also use relatively few cardboard boxes (lower cost, not seen by camera, etc.).

Your job is to:

- determine what size boxes to use
- determine how many boxes to use
- determine how the boxes will be stacked
- determine if any modifications to the boxes would help
- generalize to different combined weights (stunt person & motorcycle) and different jump heights

Note that, in "Tomorrow Never Dies", the James Bond character on a motorcycle jumps over a helicopter.

PROBLEM B: Gamma Knife Treatment Planning

Stereotactic radiosurgery delivers a single high dose of ionizing radiation to a radiographically well-defined, small intracranial 3D brain tumor without delivering any significant fraction of the prescribed dose to the surrounding brain tissue. Three modalities are commonly used in this area; they are the gamma knife unit, heavy charged particle beams, and external high-energy photon beams from linear accelerators.

The gamma knife unit delivers a single high dose of ionizing radiation emanating from 201 cobalt-60 unit sources through a heavy helmet. All 201 beams simultaneously intersect at the isocenter, resulting in a spherical (approximately) dose distribution at the effective dose levels. Irradiating the isocenter to deliver dose is termed a "shot." Shots can be represented as different spheres. Four interchangeable outer collimator helmets with beam channel diameters of 4, 8, 14, and 18 mm are available for irradiating different size volumes. For a target volume larger than one shot, multiple shots can be used to cover the entire target. In practice, most target volumes are treated with 1 to 15 shots. The target volume is a bounded, three-dimensional digital image that usually consists of millions of points.

The goal of radiosurgery is to deplete tumor cells while preserving normal structures. Since there are physical limitations and biological uncertainties involved in this therapy process, a treatment plan needs to account for all those limitations and uncertainties. In general, an optimal treatment plan is designed to meet the following requirements.

1. Minimize the dose gradient across the target volume.
2. Match specified isodose contours to the target volumes.
3. Match specified dose-volume constraints of the target and critical organ.

MCM Home

4. Minimize the integral dose to the entire volume of normal tissues or organs.
5. Constrain dose to specified normal tissue points below tolerance doses.
6. Minimize the maximum dose to critical volumes.

In gamma unit treatment planning, we have the following constraints:

1. Prohibit shots from protruding outside the target.
2. Prohibit shots from overlapping (to avoid hot spots).
3. Cover the target volume with effective dosage as much as possible. But at least 90% of the target volume must be covered by shots.
4. Use as few shots as possible.

Your tasks are to formulate the optimal treatment planning for a gamma knife unit as a sphere-packing problem, and propose an algorithm to find a solution. While designing your algorithm, you must keep in mind that your algorithm must be reasonably efficient.

PROBLEM C:

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Click the Title Below To View a PDF of Problem C:

**Aviation Baggage Screening Strategies:
To Screen or Not to Screen, that is the Question**



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2014 MCM Problems

PROBLEM A: The Keep-Right-Except-To-Pass Rule

In countries where driving automobiles on the right is the rule (that is, USA, China and most other countries except for Great Britain, Australia, and some former British colonies), multi-lane freeways often employ **a rule that requires drivers to drive in the right-most lane unless they are passing another vehicle, in which case they move one lane to the left, pass, and return to their former travel lane.**

Build and analyze a mathematical model to analyze the performance of this rule in light and heavy traffic. You may wish to examine tradeoffs between traffic flow and safety, the role of under- or over-posted speed limits (that is, speed limits that are too low or too high), and/or other factors that may not be explicitly called out in this problem statement. Is this rule effective in promoting better traffic flow? If not, suggest and analyze alternatives (to include possibly no rule of this kind at all) that might promote greater traffic flow, safety, and/or other factors that you deem important.

In countries where driving automobiles on the left is the norm, argue whether or not your solution can be carried over with a simple change of orientation, or would additional requirements be needed.

Lastly, the rule as stated above relies upon human judgment for compliance. If vehicle transportation on the same roadway was fully under the control of an intelligent system – either part of the road network or imbedded in the design of all vehicles using the roadway – to what extent would this change the results of your earlier analysis?

PROBLEM B: College Coaching Legends

Sports Illustrated, a magazine for sports enthusiasts, is looking for the “best all time college coach” male or female for the previous century. Build a mathematical model to choose the *best* college coach or coaches (past or present) from among either male or female coaches in such sports as college hockey or field hockey, football, baseball or softball, basketball, or soccer. Does it make a difference which time line horizon that you use in your analysis, i.e., does coaching in 1913 differ from coaching in 2013? Clearly articulate your metrics for assessment. Discuss how your model can be applied in general across both genders and all possible sports. Present your model’s top 5 coaches in each of 3 different sports.

In addition to the MCM format and requirements, prepare a 1-2 page article for *Sports Illustrated* that explains your results and includes a non-technical explanation of your mathematical model that **sports fans** will understand.

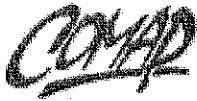
2014 ICM Problem

PROBLEM C: Using Networks to Measure Influence and Impact

Your ICM submission should consist of a 1 page Summary Sheet and your solution cannot exceed 20 pages for a maximum of 21 pages.

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MCM: The Mathematical Contest in Modeling

2005 MCM Problems

PROBLEM A: Flood Planning

Lake Murray in central South Carolina is formed by a large earthen dam, which was completed in 1930 for power production. Model the flooding downstream in the event there is a catastrophic earthquake that breaches the dam.

Two particular questions:

Rawls Creek is a year-round stream that flows into the Saluda River a short distance downriver from the dam. How much flooding will occur in Rawls Creek from a dam failure, and how far back will it extend?

Could the flood be so massive downstream that water would reach up to the S.C. State Capitol Building, which is on a hill overlooking the Congaree River?

PROBLEM B: Tollbooths

Heavily-traveled toll roads such as the Garden State Parkway, Interstate 95, and so forth, are multi-lane divided highways that are interrupted at intervals by toll plazas. Because collecting tolls is usually unpopular, it is desirable to minimize motorist annoyance by limiting the amount of traffic disruption caused by the toll plazas. Commonly, a much larger number of tollbooths is provided than the number of travel lanes entering the toll plaza. Upon entering the toll plaza, the flow of vehicles fans out to the larger number of tollbooths, and when leaving the toll plaza, the flow of vehicles is required to squeeze back down to a number of travel lanes equal to the number of travel lanes before the toll plaza. Consequently, when traffic is heavy, congestion increases upon departure from the toll plaza. When traffic is very heavy, congestion also builds at the entry to the toll plaza because of the time required for each vehicle to pay the toll.

Make a model to help you determine the optimal number of tollbooths to deploy in a barrier-toll plaza. Explicitly consider the scenario where there is exactly one tollbooth per incoming travel lane. Under what conditions is this more or less effective than the current practice? Note that the definition of "optimal" is up to you to determine.

2005 ICM Problem

PROBLEM C: Nonrenewable Resources

Select a vital nonrenewable or exhaustible resource (water, mineral, energy, food, etc.) for which your team can find appropriate world-wide historic data on its endowment, discovery, annual consumption, and price.

The modeling tasks are:

1. Using the endowment, discoveries, and consumption data, model the depletion or degradation of the commodity over a long horizon using resource modeling principles.

Modeling Forum

Results of the 1997 Mathematical Contest in Modeling

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Introduction

A total of 409 teams of undergraduates, from 226 schools, spent the second weekend in February working on applied mathematics problems. They were part of the twelfth Mathematical Contest in Modeling (MCM). On Friday morning, the MCM faculty advisor opened a packet and presented each team of three students with a choice of one of two problems. After a weekend of hard work, typed solution papers were mailed to COMAP on Monday. Nine of the top papers appear in this issue of *The UMAP Journal*.

Results and winning papers from the first twelve contests were published in special issues of *Mathematical Modeling* (1985–1987) and *The UMAP Journal* (1985–1996). The 1994 volume of *Tools for Teaching*, commemorating the tenth anniversary of the contest, contains all of the 20 problems used in the first ten years of the contest and a winning paper for each. Limited quantities of that volume and of the special MCM issues of the *Journal* for the last few years are available from COMAP.

Problem A: The Velociraptor Problem

The velociraptor, *Velociraptor mongoliensis*, was a predatory dinosaur that lived during the late Cretaceous period, approximately 75 million years ago. Paleontologists think that it was a very tenacious hunter and may have hunted

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in pairs or larger packs. Unfortunately, there is no way to observe its hunting behavior in the wild, as can be done with modern mammalian predators. A group of paleontologists has approached your team and asked for help in modeling the hunting behavior of the velociraptor. They hope to compare your results with field data reported by biologists studying the behaviors of lions, tigers, and similar predatory animals.

The average adult velociraptor was 3 m long with a hip height of 0.5 m and an approximate mass of 45 kg. It is estimated that the animal could run extremely fast, at speeds of 60 km/hr, for about 15 sec. After the initial burst of speed, the animal needed to stop and recover from a buildup of lactic acid in its muscles.

Suppose that velociraptor preyed on *Thescelosaurus neglectus*, a herbivorous biped approximately the same size as the velociraptor. A biomechanical analysis of a fossilized thescelosaurus indicates that it could run at a speed of about 50 km/hr for long periods of time.

Part 1

Assuming the velociraptor is a solitary hunter, design a mathematical model that describes a hunting strategy for a single velociraptor stalking and chasing a single thescelosaurus as well as the evasive strategy of the prey. Assume that the thescelosaurus can always detect the velociraptor when it comes within 15 m, but may detect the predator at even greater ranges (up to 50m) depending upon the habitat and weather conditions. Additionally, due to its physical structure and strength, the velociraptor has a limited turning radius when running at full speed. This radius is estimated to be three times the animal's hip height. On the other hand, the thescelosaurus is extremely agile and has a turning radius of 0.5 m.

Part 2

Assuming more realistically that the velociraptor hunted in pairs, design a new model that describes a hunting strategy for two velociraptors stalking and chasing a single thescelosaurus as well as the evasive strategy of the prey. Use the other assumptions and limitations given in Part 1.

Problem B: Mix Well For Fruitful Discussions

Small group meetings for the discussion of important issues, particularly long-range planning, are gaining popularity. It is believed that large groups discourage productive discussion and that a dominant personality will usually control and direct the discussion. Thus, in corporate board meetings, the board will meet in small groups to discuss issues before meeting as a whole. These smaller groups still run the risk of control by a dominant personality. In an