Author's Commentary: The Outstanding River Problem Papers

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This MCM problem was inspired by a research project for the Grand Canyon National Park in Arizona, U.S.A. My collaborators and I developed a mathematical model to simulate white-water rafting traffic along the 225-mile Colorado River corridor within the national park. The National Park Service manages access to the river, guided by a document called the Colorado River Management Plan (CRMP). This research program began with efforts to revise the 1989 CRMP in the late 1990s. Our model was used as a tool by river managers at the National Park Service to explore options for scheduling rafting traffic.

At the time, every year (almost entirely over the summer months) more than 19,000 people rafted the river on trips guided by 16 licensed commercial companies, while approximately 3,500 private boaters paddled themselves down the river. Demand for access to the river far exceeded supply—a waiting list for a private river trip pass had over 7,000 names on it, and a quarter of those people had already waited over a dozen years.

The hope was that this mathematical model would provide insight into alternative management scenarios so that park managers could make smart decisions that would enable as many visitors as possible to enjoy the river, while at the same time maintaining standards for a wilderness experience.

Some simplifications were built into the MCM Problem, compared to the actual situation on the Colorado River.

- The campsites on the Colorado River are not distributed evenly throughout the river corridor. Indeed, there's a big congestion problem in a reach of the river with few campsites and many popular attraction sites. Some campsites are not suitable for motorized boats.

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- It is permissible to have more than one group camping at the same site, although the Colorado River Management Plan dictates that the schedule should minimize any camping within sight or sound of another party.

- There are two fixed-points on the river corridor—places where passengers are exchanged via hiking in-and-out of the canyon or traveling via helicopter. A trip with an exchange must make it to their site at a predetermined date and time. Otherwise, there are no assigned campsites—it's really impossible to assign a rafting trip a specified set of campsite locations because so much (flash floods, boat spills, accidents, health problems) can interfere with a party's ability to reach a certain location at a fixed time. Moreover, the river culture is such that assigned campsites would be anathema.

The model uses a Geographical Information System (GIS) to divide the river into 90-meter cells. We assigned each cell specific attributes (campsite, lunch spot, dangerous rapid, hiking trail, waterfall, etc.). We used hundreds of trip diaries and personal interviews with river guides to determine appropriate weights for the popularity of camping and attraction sites along the river corridor. Trip diaries also helped us estimate the average rate of travel of motor and oar boats through various reaches of the river (when the river corridor narrows, the water's velocity increases and so boats travel through faster). The model captures the complex dynamics of human visitors interacting with the environment and each other. It is both temporal and spatial as it carefully tracks every move that every trip makes.

Our model, titled the Grand Canyon River Trip Simulator (GCRTSim), was programmed in VisualBasic. A user can build any imaginable launch schedule and "run" the season down the virtual river. The results are then analyzed and judged against criteria established by the Park Service.

Our model leveraged a number of mathematical theories and ideas.

- *Intelligent agent theory*: Each trip has an assigned "personality" and makes all of its decisions consistent with that personality to optimize each day. Thus, a short commercial trip would be less likely to choose a long hike when it needs more time just to paddle down the river. Each trip is an intelligent agent operating within a complex system.

- *Decision theory*: Each trip makes decisions based on a fixed set of choices (e.g., to stop to camp or to continue to the next campsite). The model measures the utility gained from each choice and seeks to maximize the total utility for each trip (e.g., best campsites, key attractions, low crowds).

- *Game theory*: Strategic behavior and bargaining rules come into play as each trip seeks to influence the decisions of other trips. For example, can one trip claim a downstream campsite earlier in the day by communicating its desire with the other trips that it encounters?

- Essentially, the GCRTSim model boils down to a *constrained optimization* problem where the success of the entire season depends on individual decisions made by all of the trips, and the outcome depends on the combined strategies. For the National Park Service to manage the Grand Canyon rafting season successfully, the sum of all the individual decisions over the course of the entire season contributes to an overall utility that must be maximized.

The GCRTSim model suggested that the best solution was to expand the rafting season into the shoulder months in the spring and fall. The new CRMP was authorized in 2006, and the new approach to scheduling river trips has been in place since 2008. The number of private launches was dramatically increased without lowering the commercial use. The waiting list was converted to a lottery system that appears to be in favor with the private boaters. Yet, even with more trips being sent down the river each year, the overall crowding at any particular moment was reduced because the trips were spread out over additional months. The number of trips on the river at any one time was reduced from a high of 70 to a high of 60, so the perception of visitors is that the river is less crowded now than it used to be. It is also quieter, since the number of months in which motorized rafts and helicopter exchanges are allowed have been cut in half. A rafter going through the Grand Canyon National Park on the Colorado River will enjoy a genuine wilderness experience.

Photo Credit: Catherine A. Roberts.

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About the Author

Catherine Roberts is Chair of the Dept. of Mathematics and Computer Science at the College of the Holy Cross and Editor-in-Chief of the journal *Natural Resource Modeling*. She has an A.B. magna cum laude from Bowdoin College in mathematics and art history and a Ph.D. from Northwestern University in applied mathematics and engineering sciences. She has served on numerous committees of the American Mathematical Society and the Association for Women in Mathematics, and she is an Associate Editor of this *Journal*.