Judges' Commentary: Environmental Degradation

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Background

This year's environmental science problem in the Interdisciplinary Contest in Modeling (ICM™) challenged teams to explore the true costs associated with land-use development projects. On the surface, most firms consider only the monetary costs associated with the creation of new land-use projects; but we asked teams to consider also the environmental costs of changing the use of the land and the potential for environmental degradation, aspects typically disregarded by economists and industry. Teams sought to develop an ecological services valuation model to understand the true costs of land-use projects when ecosystem services are considered.

Economic theory often disregards the impact of its decisions on the biosphere or assumes unlimited resources or capacity for its needs. There is a flaw in this viewpoint, and the environment is now facing the consequences.

The biosphere provides many natural processes to maintain a healthy and sustainable environment for human life, which are known as *ecosystem services*. Examples include turning waste into food, water filtration, growing food, pollinating plants, and converting carbon dioxide into oxygen.

However, whenever humans alter the ecosystem, we potentially limit or remove ecosystem services. The impact of local small-scale changes in land use, such as building a few roads, sewers, bridges, houses, or factories may

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seem negligible. But add to these small projects large-scale projects such as building or relocating a large corporate headquarters, building a pipeline across the country, or expanding or altering waterways for extended commercial use. Now think about the impact of many of these projects across a region, country, and the world. While individually these activities may seem inconsequential to the total ability of the biosphere's functioning potential, cumulatively they are directly impacting the biodiversity and causing environmental degradation.

Traditionally, most land-use projects do not consider the impact of, or account for changes to, ecosystem services. The economic costs to mitigate negative results of land-use changes—polluted rivers, poor air quality, hazardous waste sites, poorly treated waste water, climate changes, etc.—are often not included in the plan. Is it possible to put a value on the environmental cost of land-use development projects? How would environmental degradation be accounted for in these project costs? Once ecosystem services are accounted for in the cost-benefit ratio of a project, then the true and comprehensive valuation of the project can be determined and assessed.

The Problem

Your ICM team has been hired to create an ecological services valuation model to understand the true economic costs of land-use projects when ecosystem services are considered. Use your model to perform a cost-benefit analysis of land-use development projects of varying sizes, from small community-based projects to large national projects. Evaluate the effectiveness of your model based on your analyses and model design. What are the implications of your modeling on land-use project planners and managers? How might your model need to change over time?

Judges' Criteria

We describe the general framework used by the judges to evaluate submissions. The judges included representatives from a diverse set of fields, including sustainability, biology, geography, applied mathematics, statistics, and engineering. Their main objective was to find and evaluate modeling that included good science and led to measurable and viable solutions. The judges were looking for papers that clearly communicated the following major components for a submission to be considered as one of the best papers:

- Above all else, we wanted students to show an **understanding of the complexity** of the problem beyond what was provided in the problem prompt. The inclusion of a well-researched and unique introduction, with elements similar to a literature review prior to the formulation of the model, indicated to judges a level of true comprehension of the criticality of devoting time to such an endeavor.

- As in all ICM problems, we expected the **formulation of a model**—in this case, an ecological services valuation model that shows an understanding of the true economic costs of ecosystem services in land-use projects. Teams had to identify the key factors that were important to their model and analysis as well as consider the inclusion of actual costs. Judges sought papers that included the qualitative analysis to augment a quantitative model.

  Ideally, judges wanted the best model to be developed, coupled with a discussion of the best proxy factors that then had to be incorporated into the model. This had to be based on data that the team had available, and not the other way around. The best papers identified what would be ideal to use, then what they could actually find, and finally how those data might not match but how it would work. A team's recognition of the limitations of the modeling process showed great maturity and confidence in their research and knowledge of ecological services and the impact land-use projects have and can contribute to environmental degradation.

- Judges wanted teams to **apply their model** of ecological services to understand the true economic costs of land-use projects when ecosystem services are considered. Judges also sought the consideration of environmental degradation in project costs. Teams then were asked to include a true cost-benefit analysis of land-use development projects of varying sizes, from small community-based projects to large national projects. Judges were looking for specific examples of either existing projects or details of a proposed project for a specific area. Teams needed to find, create, or use data to test and explain their measures and models as appropriate in this section.

  Additionally, judges were pleased with teams that addressed the reasoning behind the projects chosen. Providing the motivation and explaining the critical research done on the understanding the components of each project in the area chosen for development showed the judges a level of understanding and sophistication that set the best papers apart from the rest.

- Lastly, the contest challenged teams to **evaluate the effectiveness of their model** based on their analyses and model design. Teams needed to discuss the applicability of their model to different locations, projects, or potential need to modify their model over time. The best teams were able to incorporate a dynamic element into their model to see the changes of the land's use over time during a project build and then after completion. Additionally, the advice to project planners and managers was a critical component to the submission and offered judges insight into a team's understanding of the greater applicability of their metric.

As always, judges expected the basic elements of model formulation as well as the delineation of strengths and weaknesses of the model, the conduct of sensitivity analysis, model validation and verification, and good written communication:

- **Model Formulation Basics.** As teams developed their model, judges expected teams to include definitions of their variables, to state reasonable and necessary assumptions and to include an explanation of the process of parameter estimations. It is critically important to identify and appropriately cite sources for data or existing models used as a baseline for constructing the team's model or for comparing it to others.

- **Strengths and Weaknesses.** After modeling and analysis, judges expected discussions of the strengths and weaknesses of their model and some concluding thoughts versus just ending the paper after completing all tasks.

  In past years, the problem prompt had specifically required teams to detail their strengths and weaknesses in their model. This year did not, and therefore a discussion of strengths and weaknesses became an indicator of a deeper understanding of the aspects of modeling. Judges were encouraged by teams who provided the analysis throughout the submission versus right at the end of their report seeming as though it was an afterthought. Evaluation in terms of its strengths and weaknesses is relevant to the entire modeling process.

- **Sensitivity Analysis.** Sensitivity analysis could have been done in a variety of ways, so judges were looking closely at the rationale behind each team's approach. At a minimum, the expectation was a revisit of early simplifying assumptions. Judges also saw teams assessing the relative impacts of different types of model improvements. There was no one way but teams which attempted a sensitivity analysis to determine the robustness, flexibility, or accuracy of their model demonstrated to the judges a higher level of knowledge concerning of the impact and usefulness of their model.

- **Model Validation and Verification.** These aspects of modeling often set a great paper apart from just a good report. Validation is an important part of the modeling process, as it can instill confidence in results of help identify weakness in the model. Several papers presented a range of models from simple to complex and used a validation approach to justify the selection of one of those choices, considering the tradeoff. Judges saw teams who included the removal of some of the indicators in their model to see if their removal truly changed the output of their model. Other teams ran their model against other known metrics to see if it accurately predicted the success. Judges understood the time constraint that teams were under and therefore appreciated teams that had given it consideration.

- **Written Communication.** Every year, judges seek to highlight submissions that offer a balance of sound mathematics with well written justifications from their approach. Judges looked for implementable measures that were backed by strong research and then well explained. The strongest submissions had a clear organizational structure with equations coupled to explanations with (when appropriate) graphics to help convey complicated ideas.

Recognition of the Outstanding Papers

Due to the nature of the environmental problem, teams used varying modeling techniques focusing on different factors representing ecosystem services and how to place a value on the environmental cost of land-use development projects. Teams also selected assorted projects with different scales in diverse areas throughout the world for their cost-benefit analysis. As a result, the submissions provided great innovations and excitement for the judging panel.

The eight Outstanding papers demonstrated a nice array of modeling techniques and then showcased their model's capabilities to handle true costs, scalability, and multiple factors.

These Outstanding papers were well-written and provided clear explanations of their modeling procedures. Some demonstrated unique and innovative approaches distinguishing themselves from other papers. Others were noteworthy for either their thoroughness of their modeling or for the significance of their results. Some provided well-thought-out, implementable recommendations to project managers, perfectly tailored to the type of project or area of implementation. We would like to congratulate the eight Outstanding papers from Problem E:

- Central University of Finance and Economics, Beijing, China: "Land Counts! Better Use and Lower Cost"
- Chongqing University, Chongqing, China: "What is the Cost of Environmental Degradation?"
- Emory University, Atlanta, Georgia, USA: "Is This a Monetary Evaluation of Ecosystem Services?"
- Lanzhou University of Technology, Lanzhou, Gansu, China: "Assessment of Ecological Services"
- Nanjing University of Information Science and Technology, Nanjing, Jiangsu, China: "Ecosystem Services Matter! Sustainability is Necessary"

- Renmin University of China, Beijing, China: "Take Environmental Effect into Consideration: Cost-Benefit Analysis on Land-Use Projects"
- U.S. Military Academy, West Point, New York, USA: "Ecological Services Valuation Model: Understanding the True Cost of Land-Use Projects"
- University of Virginia, Charlottesville, Virginia, USA: "What is the Cost of Environmental Degradation?"

Summaries of the eight Outstanding team papers follow.

Chongqing University, Chongqing, China: "What is the Cost of Environmental Degradation?"

The team from Chongqing University had a standard base model derived from the literature but shined in their model extensions and applications. Using a derivation of the Cobb-Douglas equations, the team was able to calculate net primary production with shadow price analysis applied to four different projects.

Initially, the judges were concerned that analysis of the four projects—a house, a subway, a steel mill, and a bridge—was without any context as to where these projects might occur. However, unlike other models, their model is land-type dependent. Each project was accompanied by extensive temporal cost-benefit analysis as shown in **Figure 1**, as well as calculations of capital and technological input costs, employee payment, maintenance costs, revenue, social benefit, and environmental degradation.

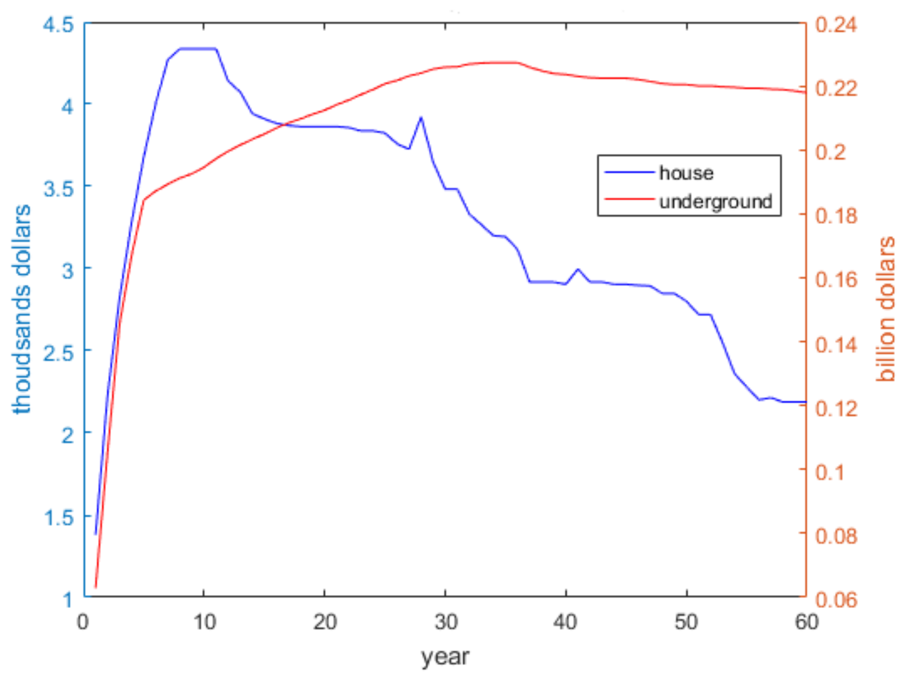

Figure 1. Environmental degradation cost for a subway (curve rising over time, cost scale on right) and for a house (curve rising then falling, cost scale on left), from Chongqing University.

Judges were most impressed by this Outstanding paper's treatment of recommendations and their further discussion. After an extensive sensitivity analysis followed up by a tax discussion, the team nailed the recommendations. One of our sustainability judges lauded the team for the inclusion of all aspects of environmental impact, demonstrating a deep understanding of the complexity of the problem. Their logic was very clear and left a road map for further analysis.

Central University of Finance and Economics, Beijing, China: "Land counts! Better Use and Lower Cost"

This paper received the classification of Outstanding for its readability, organization, consideration of time, and advice to project planners. This paper stood out to the judges due to its incorporation of seasonal and yearly change.

The team created a model based on work of Costanza et al. [1997] and the MEA model [Millennium Ecosystem Assessment Board 2005]. While the team's model was not novel, the framework of their model, depicted in **Figure 2**, was clearly outlined and the discussion of their results was well written.

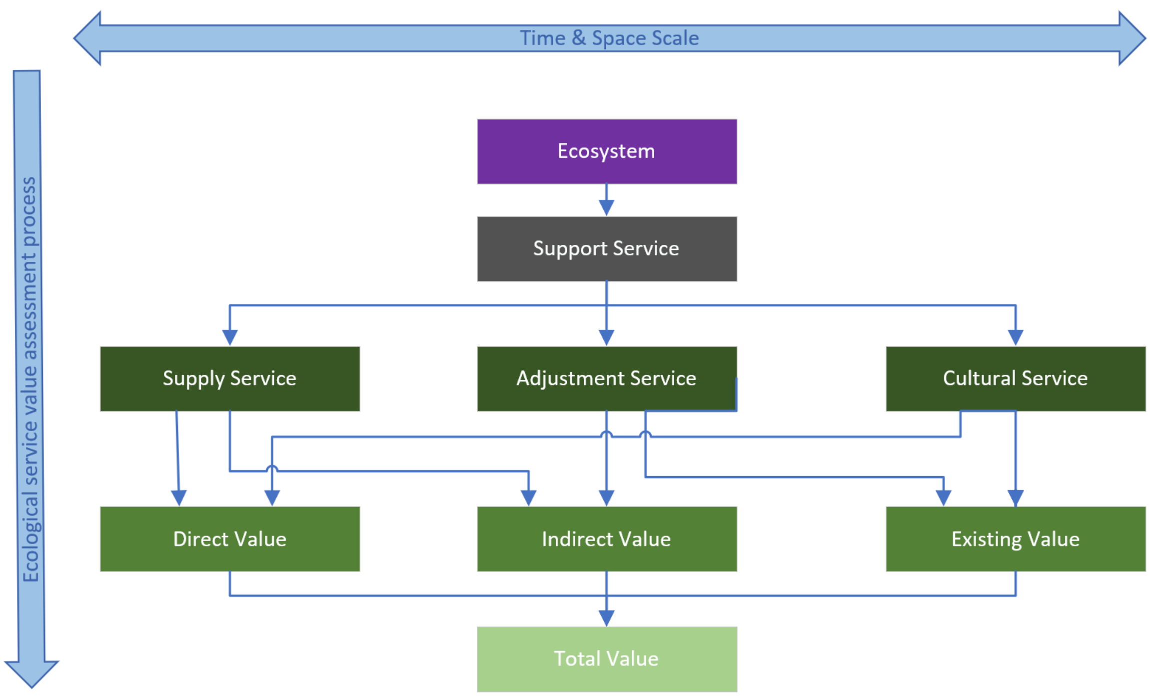

Figure 2. Model framework for Central University of Finance and Economics.

To test their model, the Central University team measured the value of ecological services in 14 regions of China, taking into account the impact of total land area on ecological value assessment. After testing their model, they applied it both to a large project and to a small project. Based on their results, they made thoughtful recommendations to planners and conducted a cost-benefit analysis.

The judges were impressed by the team's accounting for seasonal change by considering factors such as change in temperature and rainfall throughout the year. The team had a well-written and organized paper that addressed change in time in a way not seen in other papers. For this, they received a rating of Outstanding.

Emory University, Atlanta, Georgia, USA: "Is This a Monetary Evaluation of Ecosystem Services?"

This Outstanding paper pleased the judges with a straightforward description of their model and a clearly written paper. Not only did the team consider several case studies but they also incorporated the change in ecological service over time.

To evaluate the cost of ecological services, the Emory team included models for carbon sequestration and water filtration and purification. They considered both an urban proximity index and an eco-friendly index. These indices corresponded to a location's proximity to an urban setting and to the location's effort to reduce its carbon footprint respectfully.

Six different cases studies were conducted of varying size and location. Making use of The Economics of Ecosystems and Biodiversity (TEEB) valuation database, the team calculated the total monetary cost, taking the cost of ecosystem services into account. Their ecological costs can be seen in **Figure 3**.

Project	Ecological Cost (USD)
Road construction in Cairo, Egypt	$219
Housing in Washington, USA	$502
Facebook MPK20 in California, USA	$19,110
Road construction in Hobart, Australia	$1.7 million
Vía Verde Pipeline in Puerto Rico	$642 million
Nicaragua Canal Project	$3.16 billion

Figure 3. Economic Cost obtain by Emory University for six case studies.

For each location, the team gave the total with and without the first year's environmental service costs. Taking the percentage increase into account, the team considered whether the cost of ecosystem services had a significant impact on the total cost of the land-use project. The judges commented that there was some disconnect between the model and the values obtained for the ecological cost; however, the team clearly presented their findings in a concise and easy to read way.

The team from Emory concluded their paper by considering the accuracy of their model in the future and a discussion of sensitivity analysis. While the judges felt that the paper lacked advice to project managers and planners, the team's ability to clearly describe their model and results was worthy of the designation Outstanding.

Lanzhou University of Technology, Lanzhou, Gansu, China: "Assessment of Ecological Services"

Judges always seek out well-researched submissions with unique models based in the philosophy of the literature and on the reality of the available data. The team from Lanzhou University of Technology had such a submission. They impressed the judges in their creation of a metric based on the environmental components shown in **Figure 4**, as well as in their acknowledgment of data abnormalities (in some of the factors that they wished to incorporate and in others that they did not include due to lack of a reputable source).

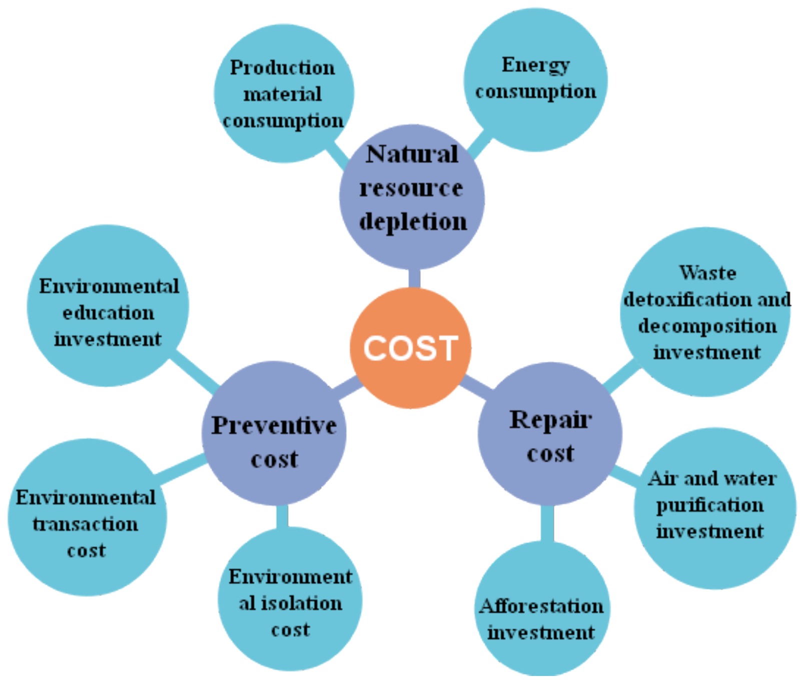

Figure 4. Lanzhou University's graphic depiction of their unique cost metric incorporating natural resource depletion, prevention costs, and repair costs.

The team began with a nice restatement of the problem and included both costs and benefits presented from both sides of the argument before the creation of their own metric for natural resources lost. They carried this detailed self-created model throughout the entire submission, adding for more extensive analysis, when needed, aspects such as time. Judges applauded this approach, since many other teams created many separate models to handle different aspects of the problem.

The only caution for this Outstanding paper was the use of their analysis for their recommendations. Although grounded in their unique and tested model, the recommendations were very technical. Instead, the team should have taken their quantitative results and put them into tangible recommendations that would be truly implementable by project managers.

Overall, Lanzhou University's treatment of the overall problem from differing perspectives led to the creation of a solid, scalable, and adaptable model which should stand as an example for future teams as they seek to tackle environmental problems.

Nanjing University of Information Science and Technology, Nanjing Jiangsu, China: "Ecosystem Services Matter! Sustainability is Necessary"

The team from Nanjing University of Information Science and Technology conducted solid analysis throughout and submitted a well-written paper. The judges want to recognize this Outstanding submission for its initial analysis and inclusion of how we need to consider the element of time in our analysis for the true understanding of the impact of ecosystem services in a particular site.

The team identified a variety of indicators from the categories of provisioning services, regulating services, biotope services, and cultural services, based on the Millennium Ecosystem Assessment [Millennium Ecosystem Assessment Board 2005]. The team then utilized the entropy-weight method to determine the weights of each before compressing 11 total indicators into four comprehensive variables. The judges appreciated their description of the process and their normalization of weights to determine a true intensity evaluation, which also allowed the team to classify each ecosystem service index in terms of the appropriate levels for weak, moderate, or strong impact.

The judges praised the concluding analysis, in which the team used vector regression to integrate the temporal requirement, and their inclusion of a detailed discussion of each project with change over time, as shown for one example in **Figure 5**.

Although the projects included were generic, the sustainability analysis and then the comparison of each project with and without the consideration of ecosystem services was excellent. The team from Nanjing University truly utilized descriptive graphics coupled with supporting explanations to communicate clearly the impacts and their recommendations for each project.

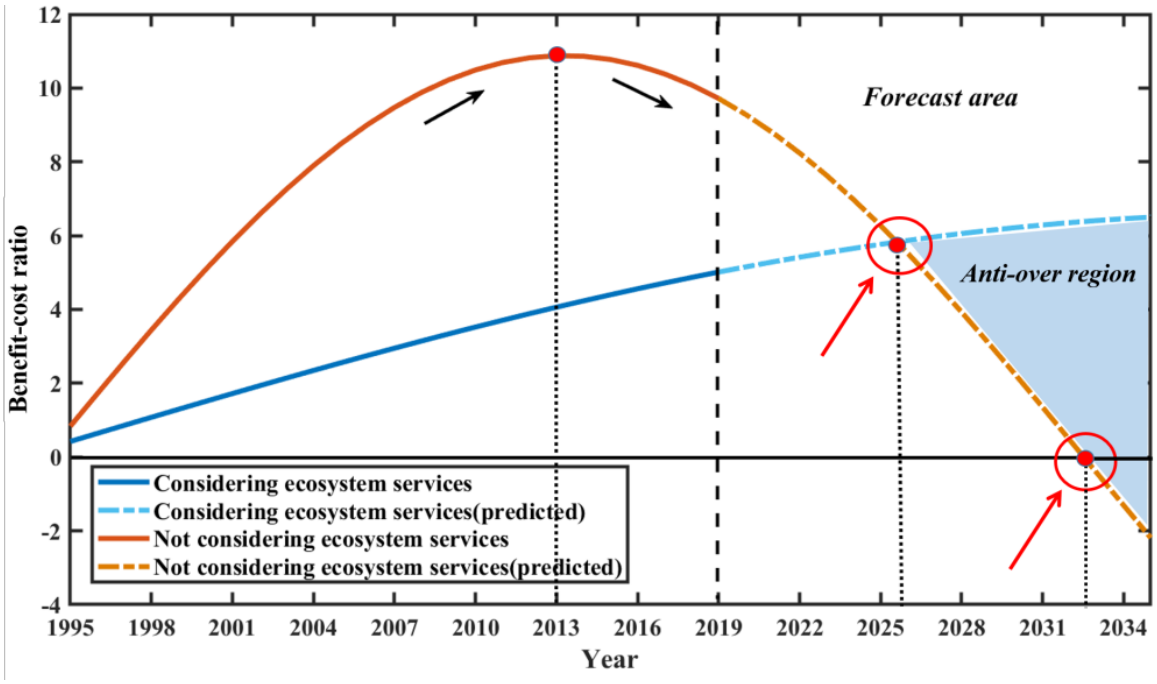

Figure 5. Cost-benefit ratios for one project from the Nanjing University of Information Science and Technology.

Renmin University of China, Beijing, China: "Take Environmental Effect into Consideration: Cost-Benefit Analysis on Land-Use Projects"

The Outstanding submission from Renmin University stood out for a straightforward cost-benefit model that included an aspect of time from the beginning, plus their tremendously detailed explanation and analysis of two projects of different scales from different areas of the world. Including the dynamical nature of the problem from the start of the analysis indicated to the judges that this team really understood that short-term implications of a project on the environment contrast with some of the lasting impacts on ecosystem services.

Although the only temporal analysis was two models that built upon each other to account for short-term, and then long-term, environmental degradation, the team nicely explained why this is not just an economic issue. They explained the necessity for the inclusion of the costs to mitigate negative results of land-use changes. Their models for short- and long-term impacts on ecosystem included different factors, with the long-term model truly focused on the environmental costs, as shown in **Figure 6**, as opposed to the short-run costs balanced between economic and environmental costs.

Their models were applied expertly to a modern small-scale paper mill in China and then to a long-term analysis of the expansive electric power development by the Tennessee Valley Authority (TVA). The use of diverse

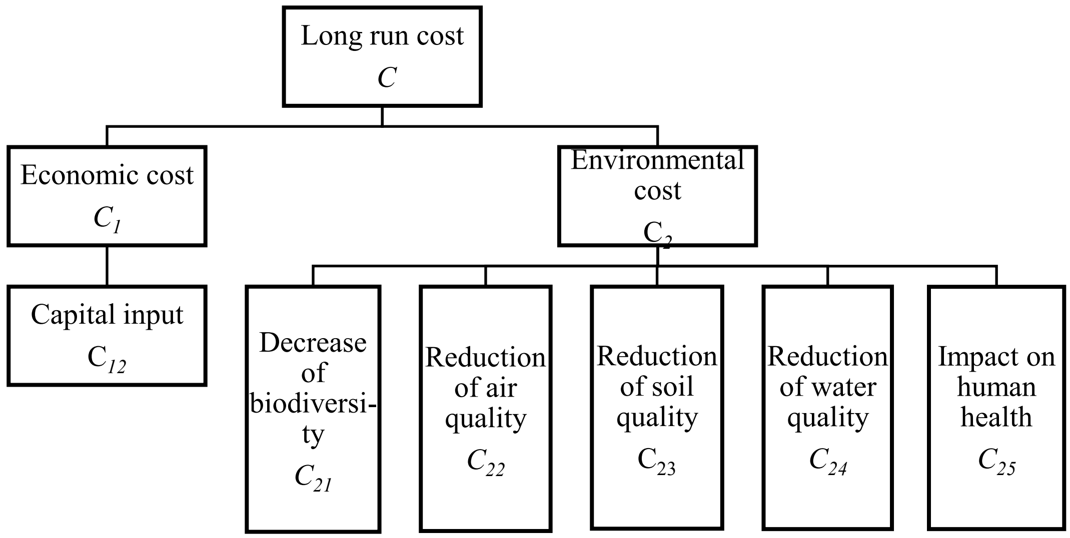

Figure 6. Long-run cost schematic from Renmin University.

application projects—modern vs. historical, small vs. large-scale, built-up area vs. rural expansive region, and from different areas in the world—really allowed the team to showcase the nice features and flexibility of their model. The use of the TVA allowed them to include a historical perspective on the decision to build electric power in the United States. This analysis led the team to a nice discussion of their identified strengths but, more importantly, the weaknesses in their formulation. Judges appreciated their honesty in the critique of the data utilized for the creation of their weights, as well as the ambiguity in boundaries between short and long term.

U.S. Military Academy, West Point, New York, USA: "Ecological Services Valuation Model: Understanding the True Cost of Land-Use Projects"

The team from the U.S. Military Academy was selected as this year's Rachel Carson Award winner. This award honors an American conservationist whose book *Silent Spring* initiated the global environmental movement and whose work spanned many disciplines concerned with local and global environments [Carson 1962]. This award is presented to the team for their excellence in using scientific theory and data in its modeling.

The judges praised this team for their well-thought-out, simple model based in the reality of the complexity of the issue at hand. The team spent time through the examination of their project on the cost to an individual project manager or business owner as opposed to the price necessary to preserve the value of ecosystem services, which are owned by all in the surrounding community. They proposed a method of converting lost environmental services into Quality-Adjusted Life Years (QALYs), which may then be converted into dollars as necessary. This incorporation of the human aspect, and not simply just dollars, provided unmatched multidimensional considerations and understanding by the team.

Although the actual model presented was simple, the detailed use of the concepts in two specific future projects was outstanding. The analysis for each project consisted of a breakdown for each indicator on the value for the particular project, as well as the shadow price or tradeoff cost for an increase in the indicator, in terms of both QALYs and dollars. The 16 indicators were broken down into three classifications for the overall ecological services of provisioning, regulating, and cultural.

The judges found the best analysis within the team's counterarguments section, where the team discussed the limitations and critiques of their methods as well as other methods that exist today. For example, the team considered restitution calculations that currently are based on the cost to add that service, but should—as specified by the team—be based on the future impact, not just the present.

Overall, this submission showed to the judges a deeper understanding of the interconnectedness of the human experience and the ecosystem services by examining the current theory and evidence to create a simple model to account for the true impact of environmental degradation done through the implementation of projects on our valuable land.

University of Virginia, Charlottesville, Virginia, USA: "What is the Cost of Environmental Degradation?"

The Institute for Operations Research and the Management Sciences (INFORMS) selected this submission from the University of Virginia as this year's outstanding INFORMS winner for Problem E. The INFORMS designation is given to a team whose modeling and analyses best exemplify the style and content reflected in the professional practice of operations research. This submission was unique in the team's choice to use a differential equations model.

Their model was based on a logistic growth function to predict the impact of projects on the value of the land in terms of ecosystem services. The choice of such a formulation was based solidly on the fact that the ecosystem is a complicated interrelated system; and although impacts on it may initially grow exponentially, they cannot do so forever. The environmental nature of the problem resulted in their using a differential equation model that limited exponential growth.

Another unique aspect of the model was the understanding of land use over time and how it transitions naturally, with or without human implementation of projects. The team understood that they needed first to evaluate the existing land not just based on the type of land but also on its quality, which was a truly unique perspective. Additional consideration was given to the valuation of the land and the physical area of the land.

The judges appreciated the scope of the three different projects that the team considered—the building of steel production factories, regreening of a desert, and the creation of a panda habitat—one very traditional, one with mixed opinions, and one truly meant to be environmentally conscious.

Take the more controversial regreening project, as seen in **Figure 7** in the team's cost-benefit analysis, where the independent variable is area of the project. The project loses money (from the status quo established for the land) until the scope of the project expands to 4285 km^2, it and reaches maximum gains at 5980 km^2. The team accompanies their graphics by thoughtful interpretations of the implications in terms of the context of the problem as well as the mathematical analysis.

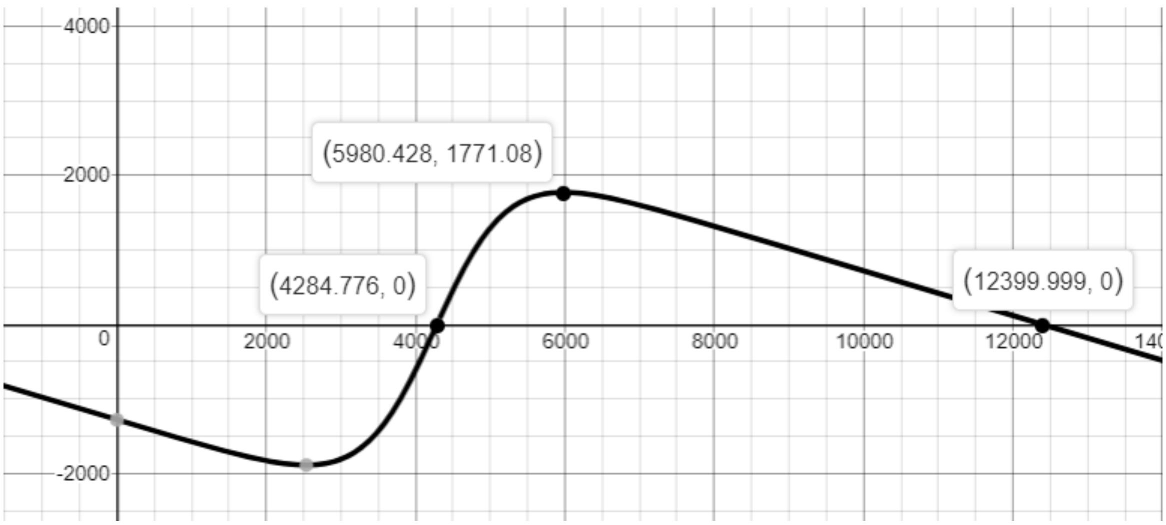

Figure 7. Cost-benefit plot of the Kubuqi Greening Project from the University of Virginia.

The team's discussion of parameter estimation, initial conditions, and intercept analysis were components unmatched in this year's submissions. Although the team did not include a strict sensitivity analysis nor specific discussion of strengths and weaknesses, those topics were implied throughout the paper.

Recommendations to Future Participants

In the past, we have made recommendations for future participants for Problem E. We suggest looking at the details of these recommendations in the Problem E judge's commentary in last year's ICM issue [Arney 2018]. In general, the judges recommend focusing on three areas for those attempting the environmental problems during next year's competition:

- First, **make a plan** for the weekend and conduct the initial research.

- Next, **solve the problem** and all the subtasks that were stated or implied in the problem statement.
- Finally, ensure that you **present explanations and interpretations** for your solutions and recommendations.

Conclusion

This problem presented challenges to teams in the form of considering the impact of or accounting for changes to ecosystem services due to land-use projects. Only when ecosystem services are accounted for in the cost-benefit analysis for a proposed project can the true comprehensive valuation of the project be determined and assessed.

Many teams had innovative and useful ideas for some parts of the problem but were unable to satisfy all the tasks required in the problem within the time constraints. The eight Outstanding teams completed the required tasks the best and were able to communicate the results effectively. Members of all the competing teams are to be congratulated for their excellent work and dedication to interdisciplinary modeling and problem solving. The judges were truly impressed by the ability of so many to combine great modeling, well researched science and effective written communication skills to address the critical issues of future environmental degradation and its impact on ecosystem services.

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