Judges' Commentary: The Outstanding Electric Car Papers

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Introduction

The Interdisciplinary Contest in Modeling (ICM) is an opportunity for teams of students to tackle challenging real-world problems that require a wide breadth of understanding in multiple academic subjects. The difficult nature of the problems and the short time limit require effective communication and coordination of effort among team members. In one sense the real problem is how to best use each team member's skills and talents. Teams that have solved this problem usually submit solutions that rise to the final rounds of judging.

The Problem

Increasing prosperity in the developing countries is tied to an increasing demand in these rapidly growing economies for both energy and automobiles. The difficulty of meeting the increasing demand for oil and the potential environmental impact of increasing numbers of fossil-fuel vehicles are global challenges. This year's problem addressed the effect of transitioning

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from vehicles powered by fossil fuels to electric vehicles. The many aspects involved made this an especially appropriate topic for modeling. The main tasks expected of the students were to:

- model the impacts of the widespread use of electric vehicles,
- estimate how much oil the world would save by widely using electric vehicles,
- estimate the amount and type of electricity generation needed, and
- discuss the role governments should play to ensure safe, efficient, effective transportation.

Overall, the judges were impressed both by the strength of many of the submissions of individual teams, and by the variety of approaches that students used to address the questions that were posed by the ICM problem.

Judges' Criteria

To ensure that individual judges assessed submissions on the same criteria, a rubric was developed. The framework used to evaluate submissions is described below.

Executive Summary

It was important that students succinctly and clearly explained the highlights of their submissions. The executive summary should contain a brief description of the modeling approach and the bottom-line results. The remaining report provides a more detailed statement of the contents of the executive summary. One mark of an outstanding paper was a well-connected and concise description of the approach used, the results obtained, and any recommendations.

Modeling

Multiple models were needed to determine the amount of oil saved and how the electricity would be generated to replace this energy. The assumptions needed for these models and the development of these models were important to evaluating the quality of the solutions that were submitted. The better submissions explicitly discussed why key assumptions were made and discussed how these affected the model development. The stronger submissions presented these discussions as a balanced mix of mathematics and English rather than as a series of equations and parameter values without explanation.

Science

The conversion from fossil fuel to electric vehicles involves many scientific and technological issues related to the different methods of producing electricity, how this energy is efficiently transmitted and stored, and how it can be effectively used to power vehicles. In addition, all these areas will experience significant technological improvements in the future. Understanding these issues and trends was very important in creating models with meaningful output.

Data/Validity/Sensitivity

Once the model has been created, the choice of input data and checks on the accuracy and robustness of the solution help to build confidence in the problem approach. Sensitivity analysis to determine the relative rates of change can often be more meaningful than specific output values.

Strengths/Weaknesses

A discussion of the strengths and weaknesses of the developed models is where students truly demonstrate their understanding of what they have created. The ability of a team to make useful recommendations fades quickly if they do not understand the limitations of their assumptions or the implications of their modeling methodology. A simple model that a team can understand and explain is better than a complicated equation pulled out of context from the literature.

Communication/Visuals/Charts

Although mathematics is a precise language used in science and engineering, it is not widely understood outside these disciplines. To clearly explain solutions, teams must use multiple modes of expression including diagrams and graphs, and, in the case of this competition, English. A solution that could not be understood did not progress to the final rounds of judging.

Recommendations

Teams were specifically asked to discuss "the roles that governments should play" and whether the use of electric vehicles is "an important part of an overall strategy to address global energy needs." The ability of teams to evaluate the results of their analysis and make recommendations was important in identifying strong submissions.

Discussion of the Outstanding Papers

Many teams used differential equations, often with simulations, to model the growth of electric vehicles and associated economic impacts. The Analytic Hierarchy Process (AHP) was a common method for addressing the electricity generation mix to most benefit the environment, business, society and individuals. Some chose to model using a few representative vehicles, while others worked at the macro level. As a result, the submissions this year were diverse and interesting to read.

Submissions that did not reach final judging generally suffered from one or both of two shortcomings:

- Some lacked any real mathematical modeling to support their conclusions and recommendations.
- Others had sophisticated and potentially sound models but either failed to clearly present the models or failed to connect them to the science and use them in making recommendations.

In general, poor communication was the biggest discriminator in determining which papers reached the final judging stage. Although the Outstanding papers included different aspects of the basic issues in their approaches, they all addressed the problem in a comprehensive way. The papers were well-written and presented clear recommendations. In several, a unique or innovative approach distinguished them from the rest of the finalists. Others were noteworthy for either the thoroughness of their modeling or exceptionally well communicated results.

- The Northwestern Polytechnical University submission titled "Can Electric Vehicles Be Widely Used?" presented a series of models that flowed from predicting the future number of vehicles, predicting the proportion of different types of vehicles, then mapping this to demand for electricity. An optimization model was then used to determine the best mix of types of electricity production. These results were then used to determine future trends in CO_2 production and oil savings. Weak submissions often show poor transitions as pieces of the report that were done by different individuals or groups come together. This team's report has a smooth progression of model development. They also apply these models to three countries, showing that future trends depend on political and economic contexts.
- The "What Will the Electric Vehicle Bring to the World?" paper by Southeast University uses a Bass diffusion model to predict the increase in the number of electric vehicles sold. They use a neural network model to predict overall vehicle demand, and then combine the results to use in predicting changes in oil consumption and CO_2 emission. The paper stood out for this unique approach, in which the situation was modeled

as optimization of an "ant colony." Health and environmental effects are considered in their optimization model for electricity generation.

- The paper from the South China University of Technology titled "Can Electric Vehicles Be a Shining Star of Tomorrow?" begins with the development of a life-cycle cost model. The model is used to identify the factors that are most important for electric vehicles to increase their share of the vehicle market. A diffusion model is later used to predict the transition from conventional vehicles to electric vehicles. An Analytic Hierarchy Process (AHP) model is used to determine the appropriate proportion of different types of electricity generation. The team also analyzes the sources and patterns of dispersion of pollutants associated with conventional and electric vehicles. Although somewhat compartmentalized, this paper is well written and considers a broader set of issues through the use of the life-cycle cost and pollutant dispersion models.

- The Humboldt State University submission titled "Electric Cars as a Widespread Means of Transportation" models the transition from fossil fuel vehicles to electric vehicles using a competition model represented as a system of ordinary differential equations. Team members examine a number of scenarios as part of their sensitivity analysis. The graphs showing their analysis of oil and electricity consumption under five different cases are very well done, and the paper was among the best in terms of communicating results from the models.

- The "Putting the Spark Back in the Electric Car" paper by the North Carolina School of Science and Mathematics uses a polynomial model to predict future demand for vehicles and coupled differential equations to represent the transition from fossil fuel to electric vehicles. An optimization model determines the amount of electricity generated by each power generation method. Finally, these models are joined together into a model that uses different amounts of government incentive funding to initially incentivize the transition from fossil fuel to electric vehicles. The result allows governments to minimize the total cost of the transition. The team's cellular automata approach was another of the unique methods that distinguished some of the Outstanding papers.

- The paper from Zhejiang University titled "An Analysis of the Future Development of Electric Vehicles" begins with a model of the interactions among oil prices, tax rates, and demand for different types of vehicles. A large portion of the paper focuses on the team's optimization model, which goes beyond considering only different types of electricity generation. Their model considers all forms of energy sources and allocates them among different energy uses. The objective function minimizes the total environmental cost. They analyze several versions of the model to gain insight into the problem and make recommendations.

Conclusion

There were a large number of strong submissions this year, as evidenced by the number of Outstanding papers. This can make judging difficult. However, it is gratifying to see so many students with the ability to combine mathematics, science, and effective communication skills in order to understand a problem and recommend solutions. We look forward to next year's competition, which will involve network science.

Recommendations for Future Participants

- **Answer the problem.** Weak papers do not address a significant part of the problem (e.g., electricity generation of government recommendations). Outstanding teams cover all the bases and then go beyond.
- **Time management is critical.** Every year, a large number of teams do an outstanding job on one aspect of the problem, then "run out of gas" and are unable to complete their solution. Outstanding teams have a plan and adjust as needed to submit a complete solution.
- **Coordinate your plan.** It is pretty obvious in many weak papers how the work was spilt between group members, then pieced together into the final report. For example, the output from one model doesn't match the input for the next model or a section appears in the paper that does not fit with the rest of the report. The more your team can coordinate the efforts of its members, the stronger your final submission will be.
- **The model is not the solution.** Weak teams create a model, then stop. Outstanding teams use their models to understand the problem and recommend a solution.
- **Explain what you are doing and why.** Weak teams tend to use lots of equations and few words. Problem approaches appear out of nowhere. Outstanding teams explain what they are doing and why.

About the Authors

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