Judges' Commentary: Drowning in Plastic

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Background

The growth of plastics in the last 65 years has surpassed any other manufactured material [Geyer et al. 2017]. Plastics are part of our everyday life. Electronics, medical devices, food packaging; these items are all made up of plastic. While the world has significantly benefited from the invention of plastic, the increase in production is also having a negative effect on our environment. Plastics are not easy to break down or dispose of. Most plastic waste ends up in landfills or the natural environment [Geyer et al. 2017]. Current trends predict that by 2050 oceans will be filled with more plastics than fish [Jambeck et al. 2015]. To handle the plastic waste problem, we need to slow the production of plastic and develop ways to regulate plastic waste properly.

The ICM Problem

This year's problem asked teams to address this environmental crisis caused by the production and mismanagement of plastic waste. The goal was a global plastic waste plan to minimize the environmental impact

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within the realistic confines of the current plastic industry and plastic waste pollution problems.

Teams had to:

- **determine the levels of plastic waste that can be safely mitigated** without further damaging the environment. This would effectively set a target goal, since anything below this level should not impact the environment further.
- **understand the factors that limit the ability for the global waste production to fall** into safe levels. If it were simple to decrease production or switch it to environmentally safer means, then why haven't we done so? Plastics are used in so many products; which are critical to be made from plastic and which can be made from alternate materials? What is the impact of those alternatives, in terms of environmental or economic costs? Much of the waste seems to be from single-use plastics, such as bottles, bags, straws, etc.; so is it possible to just no longer make these products? What is the impact on human day-to-day options? Overall, the way people live is not ubiquitous, so considering the ability for different countries or regions to adapt to changes will vary when considering the global issue.
- combine the goal level with the limiting factors to **create an achievable target** for minimal global waste production of single-use or disposable plastic products. It is unlikely that we can simply stop producing plastic products—a fact that should be identified as among the limiting factors—so the target goal may not be achievable. How close could we come? What might we need to give up to push that level lower? What are the true barriers that we cannot push below, even with human compliance?
- **address the inequity of problem** in terms of the costs and the benefits across the global landscape. Are there those that will be disproportionately affected and how do we address those issues?
- **summarize the team's results, findings, and recommendations in a two-page memo** to the International Council of Plastic Waste Management (ICM) to create a plan and timeline to achieve the minimal possible global plastic waste level. To be comprehensive, it is important for the team to identify barriers that the plan attempts to address and ways to meet it faster.

Overall, the analysis should comprise the tasks above in a timeline with realistic recommendations based on the modeling.

Judges' Criteria

First and foremost, judges looked for papers that are written well. Modeling choices must have justified descriptions, results explained clearly from their model, and strengths and limitations of the model included with sensitivity analysis. The modeling process in this problem required the team to describe clearly how they determined a plastics waste level that could safely be mitigated from the environment. The rationale behind what is deemed to be environmentally safe was critically important. Teams should have identified factors that limited the ability to reach this safe level and used these factors to create a realistic timeline to achieve global minimum waste. Teams that understood the complexity of the problem and had a thoughtful discussion of the equity among nations or regions pleased the judges. Below we provide commentary on several components of the problem as well as discuss how stronger papers addressed these components.

Assumptions

The inclusion of assumptions is an important part of the modeling process. Many teams included general assumptions such as that their data were reliable. The judges were looking for teams to state more specific assumptions and address why these assumptions were reasonable and necessary for their modeling choices. Outstanding submissions connected these assumptions to their model and revisited these assumptions later in the modeling process to evaluate their impact on the model.

Memo

It is important that the memo clearly and concisely highlights the team's results. Teams who provided a succinct description of their model and results in their memo demonstrated a better understanding of the problem and overall modeling process. In the memo, judges were looking for teams to not only state a realistic minimum level of global plastic waste but also to justify why they believed this minimum was achievable. Judges appreciated when teams used a visual to present their timeline. Strong papers presented specific actions and built a clear timeline that results from those actions. They also reflected on why their timeline was appropriate and what obstacles may be faced in the process.

Environmentally Safe

Teams were asked to create a model to determine the maximum level of plastic waste that can be safely mitigated without further damage to the environment as well as discuss to what extent plastic waste could be reduced to reach this environmentally friendly level. Judges looked for papers that addressed the definition of environmental safety while also identifying factors that limit the ability to reach this level. A metric for determining an environmentally friendly level needed to be incorporated into the model. While many teams merely stated a level that they deemed environmentally safe, teams that justified this value stood out to the judges. Some interesting approaches, including using the level of exhaust gas in the environment or the population of seabirds as a proxy for measuring environmentally safe levels, were featured among the Outstanding papers.

Creativity and Complexity

This year's problem was a complex one with many factors worthy of consideration. While many teams' models did not consider the impacts of plastics beyond the space that it takes up in the environment, strong papers considered the broader impacts of plastic on the environment. These considerations ranged from impacts on food chains and species populations to the effects of micro-plastics on human health. This problem required a creative approach to address more fully the impact of single-use plastics on the environment. Judges appreciated when teams were bold enough to take a creative approach in the development of their models.

Equity

One of the required tasks in this problem was to address equity issues that arise from this global crisis. The countries or regions that have the greatest benefit from the production and sale of plastic materials are not the same as those that must mitigate the environmental damage of its waste. To distribute these imbalances more equitably required modeling teams to identify the balance and impact on a region. The most common approach that teams took in addressing this task was to apply their model to two countries and discuss the differing results. Strong papers did more than this. At the very least, they were thoughtful in their selection of countries to compare, often addressing more than two countries. Some of the strongest discussions of equity applied their model to many countries and categorized those countries by socioeconomic status, allowing the team to speak more broadly of "types" of countries in their equity discussion. Judges appreciated creative approaches to determining equity issues that resulted in a more thorough discussion.

Graphs and Figures

Graphs and figures can be incredibly useful in presenting the results of a model. Strong papers included clearly-labeled and easily-readable graphs and figures to support the models and results. Some used flowcharts to explain how a model was being developed and implemented.

Images taken from another source that did not truly contribute to the reader's understanding of the model's development or results were needlessly distracting. The contest entry is an academic paper, and images should support the model and not be there just for esthetic purposes.

As always, judges expected the elements of model process to be clear and the following elements to be present:

- **Resources and citations:** It is important for teams to identify and appropriately cite sources for their work, including data, existing models used to develop their model, literature review for ideas, and images, figures, or tables not created by the team itself. While some teams create images themselves, it may also be necessary to cite the software used to create the graphic.
- **Problem restatement:** Restating the problem is not simply a cut-and-paste of the problem prompt, but rather an analysis of the way that the team interprets the problem. Some teams choose to handle problems through a particular viewpoint, which shapes how another part may be addressed. This section is a place to craft that viewpoint, so it is clear to the reader what problem is actually being answered in the modeling work in this particular paper.
- **Model formulation:** As teams develop their model, judges expect teams to explain the reasoning behind modeling choices and why these choices are reasonable. This task includes defining variables, stating reasonable and necessary assumptions, explaining and citing sources for mathematical methods used, and explaining the methodology for estimation of parameters.
- **Model validation and verification:** Modeling teams must verify that the implementation of their work follows their assumptions and correctly implements their methodology in practice. Judges expect teams to validate their models, explain how they represent the intended work, and interpret the results in terms of the problem requirements. Doing so allows for teams to provide confidence in their results, identify weaknesses, and sometimes find verification issues.
- **Strengths and weaknesses:** After a team's modeling and analysis, judges expect discussions of the strengths and weaknesses of their model and some concluding thoughts.
- **Sensitivity analysis:** Sensitivity analysis can be done in a variety of ways, so judges look closely at the rationale behind the team's approach.

At a minimum, teams are expected to revisit their assumptions. Teams that attempt to determine the robustness, flexibility, or accuracy of their model demonstrate to the judges a higher level of knowledge of the modeling process.

- **Written communication:** Judges look for a well-written paper that clearly describes the modeling approach and results.

Recognition of the Outstanding Papers

We would like to congratulate the following five Outstanding papers from the 2020 ICM environmental problem (Problem E):

- Nanjing University of Posts & Telecommunications, Nanjing, China: "Less Waste & Better World"
- Shanghai Jiao Tong University, Shanghai, China: "An Integrated Production-Waste-Harm Model Based on Combination Prediction and Dynamic Programming"
- University of Electronic Science and Technology of China, Chengdu, Sichuan, China: "Global Disposable Plastic Waste Crisis"
- Donghua University, Shanghai, China: "Drowning in Plastic"
- Brown University, Providence, RI, USA: "Drowning in Plastic"

We give below summaries of the five Outstanding papers.

Brown University: "Drowning in Plastic" (Rachel Carson Award)

The 2020 ICM Rachel Carson Award went to the Outstanding team from Brown University. Rachel Carson was a marine biologist and conservationist whose 1962 book *Silent Spring* has had a large impact on the environmental movement over the last 60+ years. The award was especially appropriate this year, given the topic of plastic waste in the ocean and the team's creative approach of modeling the seabird population.

There were several aspects of this paper that made it stand out in the judges' eyes. Most notably, the team's central idea was to model seabird population as a proxy for measuring the health of the oceanic environment. The latter is difficult to measure and even harder to quantify, especially given the limited amount of time that teams have to research the problem, build a model, and write a quality paper. The team cited literature supporting this simplifying assumption and made a compelling argument in favor of their bold decision. The effect was that the team could focus on modeling the population of seabirds, which is more concrete and straightforward.

The team used a linear differential equation to model seabird population starting from the year 1950, which is approximately when the use of plastics started to become widespread. In addition to considering birth and death rates, the team added a term that accounted for the impact of plastic waste on the seabird population. They then used this model to make predictions on the future success or failure of several policy recommendations, as shown below in **Figure 1**.

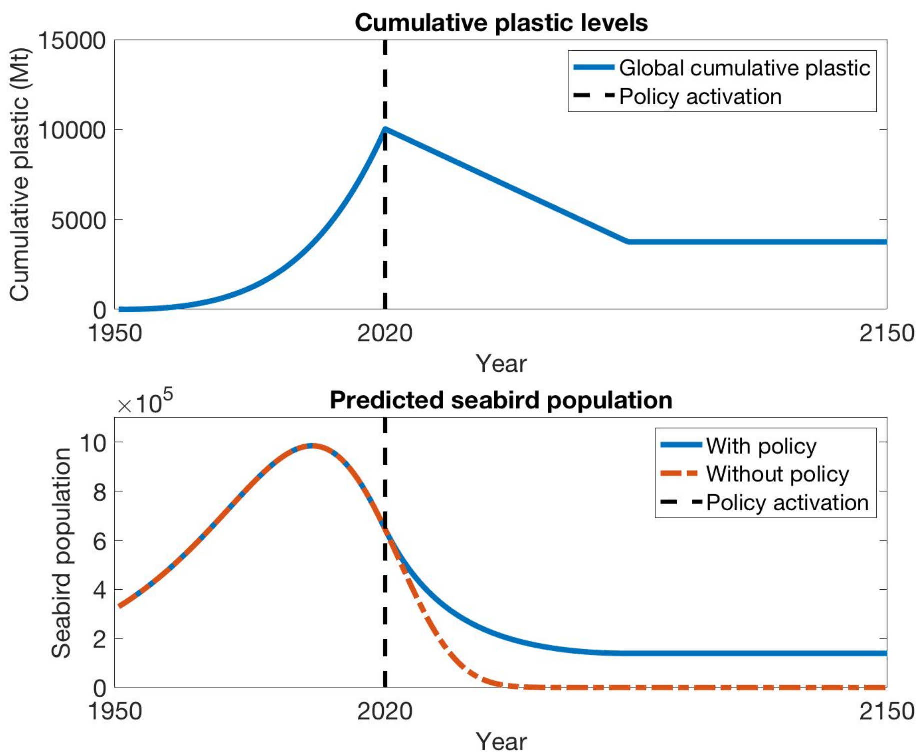

Figure 1. Impact of cumulative plastic production and policy on predicted seabird population, from the paper from Brown University.

Another aspect of the paper that stood out to the judges was the clear and logical approach that the team took in letting the assumptions guide the modeling procedure. Many teams gave a list of assumptions early in the paper, but most of these teams made the mistake of not connecting them with the modeling that followed. The team from Brown did not follow this pattern. The team stated an assumption, discussed the reasoning behind why the assumption was included, and created a model based on the direct consequences of the stated assumption. This process was repeated throughout the paper as the model developed. The judges found this approach refreshing and it demonstrated that the team had a very strong understanding of the modeling process.

No paper is perfect, especially given the challenging constraints of the ICM competition. Since the central thesis of the paper was to model seabird population, the team could have strengthened their submission by testing the validity of their differential equation model by comparing the actual seabird population from 1950 to 2020 with their model. Although they did not validate their model in this way, the team did discuss the limitation of their differential equation that it did not contain a carrying capacity term.

Overall, the team from Brown University took a bold and creative approach to model an extraordinarily complicated real-world problem. The result was a well-written paper with an almost artistic quality. The team did an outstanding job of integrating their assumptions into the modeling process and was very deserving of the Rachel Carson Award for 2020.

Shanghai Jiao Tong University: "An Integrated Production-Waste-Harm Model Based on a Combination of Prediction and Dynamic Programming" (INFORMS Award)

The Outstanding paper from Shanghai Jiao Tong University is this year's INFORMS winner for the 2020 ICM environmental problem (Problem E). The team tackled the problem with a single Production-Waste-Harm (PWH) model throughout, which they modified appropriately for each part of the problem. This single-model approach was unique and provided a more cohesive approach to this problem. Overall, this was a well-written paper and their summaries and memo were some of the best seen by the judges.

The team included several detailed flow charts to understand their modeling. The team began by using the PWH model to output annual waste and harm generated by single-use or disposable plastics. Then they integrated into the multiple impacting factors such as policy intervention and citizens' eco-awareness. **Figure 2** shows an overview of how they related these components to one another.

Finally, the team set targets and studied the impact of achieving those targets including regional differences on a global scale. This addressed many of the equity issues surrounding the plastic waste problem. They noticed the continental different with countries in South-East Asia and Mid-East Africa nearly all have serious plastic waste problems and North America and European countries only have a slight plastic waste problem. Overall, the team thought about what they were doing throughout the entire paper and clearly communicated that to the judges.

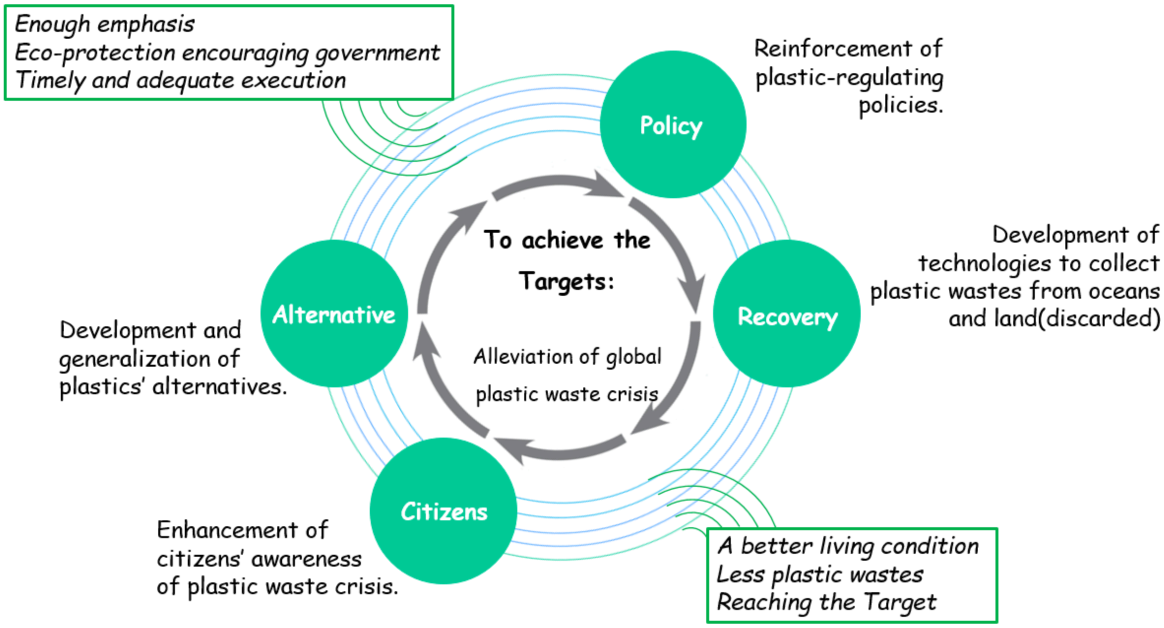

Figure 2. Shanghai Jiao Tong University team's modeling flowchart.

Nanjing University of Posts & Telecommunications: "Less Waste & Better World"

This team exhibited creativity and elements of good modeling in multiple aspects of their paper. They developed two models, between which they addressed all the tasks presented. The first model addressed disposal of plastics—recycling, incineration, and polluting to the environment. The second model involved policy-driven aspects to understand the impact on the ecosystem, society, and the economy. For each model, they provided a schematic explanation of their modeling choices, which allowed the reader to understand quickly the interactions among factors that made this dynamic model stand out.

While their models were interesting, the place where this team really excelled was in discussion of their model and its results in regard to equity. They made use of a GE matrix—a visualization technique also known as the McKinsey Nine Box Matrix, developed by McKinsey & Company for General Electric (GE) in the 1970s—to compare three levels of development of continents with three levels of effect that single-use plastics have on those continents. The team explained the concept of a GE matrix, but it would have been desirable for them to cite a source for this concept. They displayed their results by continents instead of by countries, which left the judges wanting to know more about what went into determining the numbers assigned to each continent. Despite this point, the judges were impressed by the breadth of this approach and the creative use of the GE matrix that allowed the team to have a broader discussion of equity than most of their peers achieved.

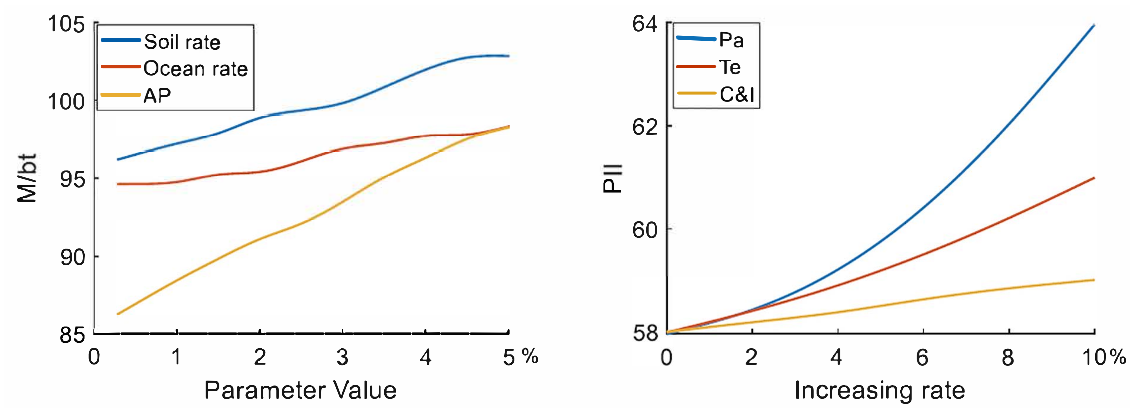

Figure 3. Sensitivity analysis conducted by the Nanjing University of Posts & Telecommunications team on each of their two models.

Perhaps the most distinguishing element of this paper was the sensitivity analysis. Unfortunately, many teams only gave a quick mention of a sensitivity analysis, and many others skipped over it entirely. This team was one of the few teams that completed a true sensitivity analysis and presented it well. **Figure 3** shows the graphs from their sensitivity analysis, which along with their clear explanations thoroughly impressed the judges. Overall, this paper had many distinguishing elements that made it an Outstanding paper.

University of Electronic Science and Technology of China: "Global Disposable Plastic Waste Crisis"

This team excelled in their ability to present a clear description of their modeling approach. To investigate the ability of a region to safely mitigate plastic waste without further damage to the environment, the team explored the relationship between Environmental Bearing Quantity (EBQ) and Environmental Bearing Capacity (EBC). Using the EBQ and EBC along with Current Waste Quantity and Current Waste Capacity, they estimated the maximum levels of single-use plastics that can be mitigated without further environmental damage. This team had a thorough discussion of the factors of waste production and waste management of disposable plastics. They also added a human component to their model by considering the risks that plastics pose to human health. The team went on to consider the impact that reaching the target of 15.88 million tons of plastics waste would have on the world. They looked at the impact not only on the environment but also on human life and the plastic industry.

The judges found the paper well-rounded. One aspect that needed to be improved was the weak list of assumptions, which did not address all the modeling choices. However, the model was explained well and was easy to follow. The team did an excellent job of including graphics, such as the one in **Figure 4**, to help the reader understand both the model and its results.

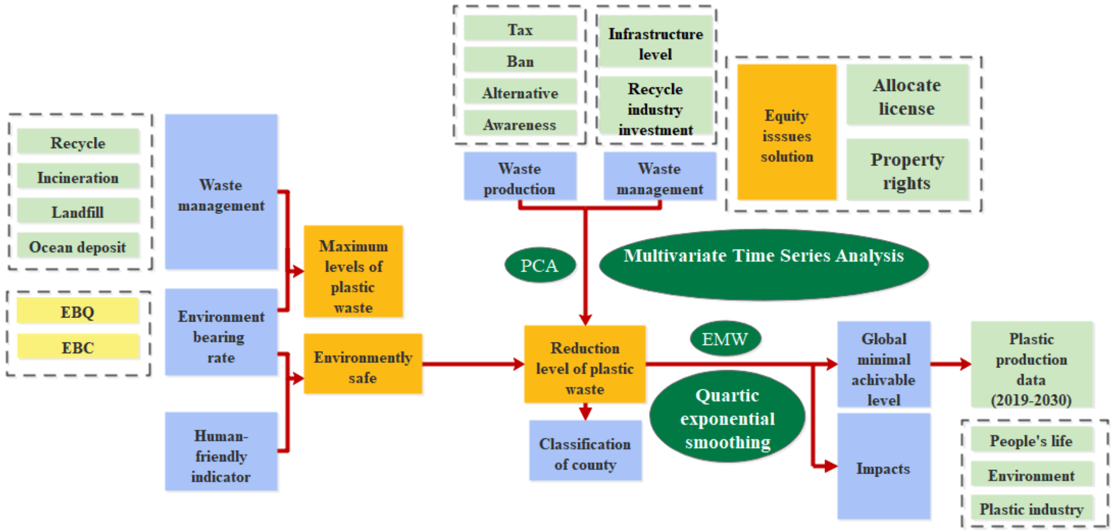

Figure 4. Modeling process of the University of Electronic Science and Technology team.

The detailed discussion of waste management conveyed understanding of the complexity of the problem. The judges were excited to see the human component of the model and the food-chain discussion—something seen in only a few papers—making it stand out among the finalists.

Donghua University: "Drowning in Plastic"

The team from Donghua University used different models to understand the maximum ecological threshold for mitigation of plastic waste (MPMV) and the plastics waste reduction capacity (PMC). The MPMV offered a unique approach, classifying plastics as seen in **Figure 5** and then using the amount of toxic exhaust gas from incineration plants to determine an acceptable level. The PMC model used a three-level method to evaluate six indicators to determine capacity to mitigate plastic. While separate models for every different aspect of a problem usually disjoints the work, the team was able to combine these models to give the volume of plastic waste mitigated, thereby showing their work to be cohesive. This team's approach allowed flexibility to analyze different aspects of the problem in determining effective strategies and recommendations.

A strength for the judges was that the team validated their results on each model and gave justifications for their selections. They used the U.S. as a validation for MPMV as a base case, because data are readily available. They compared 10 countries against an established model for ability to mitigate plastic and then pursued the analysis for Japan and Vietnam. Finally, they analyzed Singapore and Italy for the combined model so as to better understand equity. They chose these two countries of the same size to discuss how they would handle equity at a macro level and at a micro level. There was a missed opportunity for this team to interpret their model from

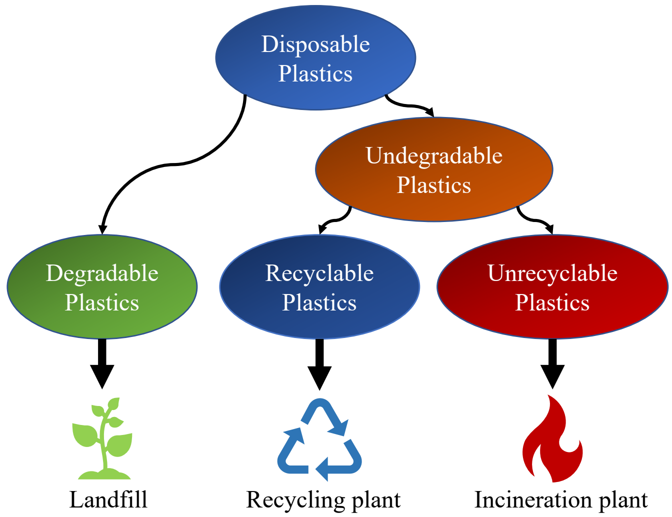

Figure 5. Classification and treatment of disposable plastics from the Donghua University team.

a social justice point of view. Overall, the judges were impressed by this team's macro and micro discussion throughout the paper.

Additionally, the team discussed the element of time in their analysis, which discussion contributed to understanding the impact of policies on achieving global targets. The 10-year projection included a proportion of country participation, which allows those target goals to be met without global compliance. This demonstrates the real difficulty of implementing global policies, even when trying to fix global problems.

The judges found this to be a well-rounded paper that demonstrated a deep understanding of the complexity of the problem through the inclusion of all aspects of an environmental impact model, accompanied by an interesting timeline in their memo.

Recommendations to Future Participants

Several past judges' commentaries have provided recommendations for future participants [Arney 2018; Arney and Farlow 2019]. The judges continue to recommend that future teams completing the environmental problem focus on three overarching areas:

1. **Make a Plan.**
   The 96-hour window of time to complete such a large modeling task is one of the many challenges teams will face. Luckily, it is one of the few challenges that teams can begin to address before the competition actually begins. Make a plan for how your team hopes to use the 96 hours. Throughout the competition your team may need to adjust the plan due to other unforeseen challenges that inevitably arise. However, having a plan to start from is crucial for success.

ICM problems are complex interdisciplinary problems. It is highly unlikely that any individual can address all aspects of the problem on their own. However, this is not an individual competition. Teams whose members work together and leverage the strengths of each individual will be more successful.

Even though the problems are complex, judges expect teams to address all aspects of the problem. However, they understand that there is not enough time to consider the full complexity of the problem and become an expert in every aspect. Addressing all aspects in some way tells the judges that your team has taken the time to do their research, understands the modeling process, and appreciates the full complexity of the problem. If, after you have done the research, you are still unsure how to handle one component then focus on what you do understand. The use of reasonable assumptions whose impact you evaluate of through sensitivity analysis can help you narrow the problem down to something that you can handle while still addressing the complexity.

2. **Solve the Problem**

   Judges often see a team attempting to use the newest, most complex model that they have encountered. Sometimes this works well; but more often than not, the team fails to explain the model in a way that shows that they truly understand the model, the problem, and the modeling process. A simple model that is explained well and creatively addresses the problem will always be more successful than a complex model that leaves the judges with many questions.

3. **Present Explanations and Interpretations**

   Communication is critically important. This competition is about solving real-world environmental problems; however, a team with a great model but without a great presentation will not be designated as Outstanding.

4. **Be Creative**

   Many papers were creative in their approach. While some aspects may have prevented them from earning an Outstanding designation, the judges want to note special features in a couple of Finalist papers:

   - "Flooded with Plastic, Make Plastic a Boat" from Northeastern University in China considered the flow of microplastics through the food chain to human consumption; this impact on human and ecological life is an important factor not found in many papers.
   - "ECIN: A Three-Dimensional Dynamic Model" from Central South University in China considered a three-dimensional model featuring environmental damage, self-regulation, and artificial regulation and how they interacted. They implemented their model on nine regions of the world to create a view of equity within the model development. Their model and development were quite strong.

Concluding Remarks

The most important feature that judges are looking for is a well-written paper. Spending time on the summary, refining the two-page memo to the ICM, justifying the modeling choices, and offering implementable recommendations based on the modeling provide a strong case for why a paper may deserve a high designation.

The judges were impressed by the variety of approaches that teams took. The five Outstanding papers had very different models. Each had at least one aspect of their modeling process that the judges found to be unique and refreshing. This fact shows that there was not just one approach that judges were looking for. Unique models that were clearly explained stood out to the judges. Stronger teams presented a cohesive treatment of the problem and did not consider each task as a separate problem. Top papers also thought critically about their results, through a sensitivity analysis or a discussion of strengths and weaknesses. Being able to reflect on your results as well as the assumptions of the model shows a better understanding of the modeling process.

While the five Outstanding papers were best in addressing all aspects of the problem by clearly presenting their model and results, the judges were impressed by the interdisciplinary modeling and written communication skills demonstrated by so very many teams from around the world. All members of all participating teams are congratulated for their hard work, dedication to interdisciplinary modeling, and their concern for the global plastic crisis.

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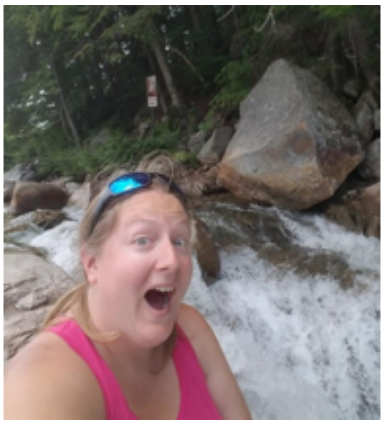
About the Authors



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Kasie Farlow is an Assistant Professor of Mathematics at Dominican College in Orangeburg, NY. She received her B.S. in Mathematics at SUNY Brockport and then her M.S. and Ph.D. in Mathematics from Virginia Tech. Kasie spent three years at the US Military Academy at West Point as an Assistant Professor of Mathematics and as a Davies Fellow. It was at West Point where she was first introduced to the ICM. Since 2016 Kasie has been actively involved in ICM, serving as a triage judge, commentary judge, site judge, final judge, and final head judge.

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