The 2024 MidMCM

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Congratulations to all the teams who participated in the fourth annual international Middle School/Level Mathematical Contest in Modeling (MidMCM). A total of 76 middle school/level teams, with up to four students each, representing 44 schools and three countries/regions, competed in MidMCM this year. The judges were impressed with the obvious time and effort that all teams put into their submissions. The MidMCM is an amazing and rewarding experience for students, advisors, schools, and judges around the world.

We applaud all participants. In the end, two teams rose to the top and were designated Outstanding Winners. The National Council of Teachers of Mathematics (NCTM) supported the designation of one of our MidMCM teams as the NCTM Award winner.

Outstanding Teams

- 15637 – Shanghai Starriver Bilingual School, Shanghai, China
  NCTM Award
- 16255 – R.J. Grey Junior High, Acton, MA, USA

The 2024 Contest

We are truly impressed by the amazing teamwork and creativity shown by participating students. The MidMCM problem, *The Modeling Musical Tour*, challenged teams to develop models that could be used to analyze a musician's past tour, plan a musician's next concert tour, and generalize their models. The variety of approaches that teams took to the problem delighted judges.

Overview

While COMAP has offered international modeling contests for over 40 years, 2024 was the fourth annual MidMCM contest held each fall. As mathematical modeling continues to expand in the school curriculum, participation in COMAP's modeling contests continues to increase.

MidMCM participants demonstrate strong mathematical modeling ability evidenced in the problem solutions and professional submissions. We applaud advisors and teachers for their work in preparing their students. Additionally, COMAP is happy and eager to assist teachers and students engage in mathematical modeling at all levels.

Results

Table 1 shows the results of the 2024 Middle School/Level Mathematical Contest in Modeling (MidMCM).

A total of 258 students participated in the 2024 MidMCM. A wide range of schools competed, including teams from Canada, China, and the United States of America. The 27 teams from the United States represented eight states. Submissions included 49 foreign teams with China representing about 94% of those teams.

Our MidMCM participants are quite diverse. Of the 258 student participants this year, 99 (38%) self-identified as female, 149 (58%) self-identified as male, and 10 (4%) self-identified as non-binary. We hope that all students enjoyed their contest experience and continue to pursue Science, Technology, Engineering, Arts, and Mathematics (STEAM) in their studies and beyond. We welcome all levels of middle school or middle level grade students to participate in the MidMCM. Success in the contest requires only middle school/level mathematics skills and concepts and a desire to work on a team to solve a real-world problem.

Rules

Teams of up to four students all under the age of 14½ years old can schedule their own working time within the two-week contest window. Our 25-page limit for papers results in well-written and well-organized solution papers. Teams must choose what information, modeling, and graphical support is necessary to present their full analysis of the problem within 25 pages.

Category	Number	Percent
Outstanding	2	3%
Finalist	5	7%
Meritorious	7	9%
Honorable Mention	25	33%
Successful Participant	36	47%
Unsuccessful Participant	1	1%
	76	

Table 1: *2024 MidMCM Judging Results*

One important rule is that students may *only use the members of their own team along with inanimate (non-living) sources* to complete the contest problem. Students may not use their teachers or advisors, any chat rooms, electronic communication, or social media sources. Unfortunately, each year we have some teams that do not understand this rule. Some examples that violate this rule are:

- Contacting an expert in a field or an author of one of the referenced sources.
- Gathering data from people outside of your team through the use of an interview or a survey or a questionnaire.
- Using solutions shared electronically by other teams or by organizations.

Again, only the team members may contribute to the solution through their own knowledge and work, and by using inanimate resources (e.g. research articles, web sites, textbooks, journals, publications). Additionally, COMAP will never require that you purchase additional materials or information to be successful in the MidMCM. The materials and information provided by COMAP, along with your own team's knowledge, skills, and perhaps a bit of research using allowed references, is all that you need for success.

Judging

All contest submissions are electronic. This allows a high quality and diverse judging pool to simultaneously judge papers. In December 2024, we conducted our first round of contest judging with judges from the U.S. states of New Jersey, Ohio, and Washington. Each paper is read and scored by two preliminary judges. We thank these judges for their careful review of our MidMCM submissions.

All judging is blind with respect to any identifying information about the participants or their schools. Preliminary judges rank papers as Finalist, Meritorious, Honorable Mention, and Successful Participant. Judges sent all papers ranked as "Finalist" or "Meritorious" to Final Judging. Each paper is judged by a minimum of two judges to ensure the best submissions are identified for closer evaluation in final judging. This year, 23 papers went to Final Judging for a panel of three judges to consider. These 23 papers were the best submissions from the preliminary round. At final judging the judges decided which papers were designated as "*Meritorious*", "*Finalist*", and from those chose the *"best of the best"* as Outstanding papers. Two papers earned the Outstanding award with 5 more being designated as finalists and 7 additional papers being designated as Meritorious.

The Future of Math Modeling and The MidMCM

The first MidMCM was held in 2021 to increase student proficiency in mathematical modeling for middle school/level students. Mathematical modeling continues to grow at all school levels around the world, and we recognized that middle school/level students are modeling too. The MidMCM has been held concurrently with HiMCM in the fall each year so that middle school/level students have the opportunity to demonstrate their mathematics and modeling abilities. Please visit **www.MidMCM.org** for more details and the results of this contest each year.

The MidMCM allows students to model their world by using mathematics tools and quantitative reasoning skills that represent, understand, and explain real world events. Through participating in these contests, students look for and leverage patterns, apply critical thinking, use an iterative problem-solving process, and see how mathematics is connected to daily life. As students work through the problems, they gain confidence in their own mathematical abilities and learn to work in a team with other students. This also helps students realize that mathematics is not just a subject in school, but how it is relevant to daily life and can also be a collaborative and creative endeavor.

Advisors and students often ask what level of mathematics is required, and what special programming or coding skills are needed for the contest. Our MidMCM problems require only middle school/level mathematics. The problems are written to be open ended, so the judges see a variety of approaches in the final submissions. Students should apply the mathematics they understand and are able to explain in their solution analysis, as the ability to clearly communicate their methods and rationale is valued in final judging.

Advisors need only be motivators and facilitators to encourage students to be creative and imaginative. COMAP encourages all middle school STEAM faculty to get involved, encourage your students to be problem solvers, make STEAM relevant, and open the doors to future success. We want to partner with teachers as we continually strive to improve the contest and make it accessible and impactful for all students. We encourage teachers and team advisors to explore past problems with their students anytime throughout the year to prepare them for participating in the competition. All past COMAP competition problems can be accessed at mathmodels.org. Any school can enter, and each school can enter as many teams as that school desires. MidMCM has no restrictions on the number of total schools or the numbers of total teams from any one school or overall.

More than just learning skills and operations, mathematics is both an art and a science. Through mathematical modeling, students learn to think critically, communicate effectively, and become confident and competent problem solvers. Success is not only about the procedural technique used, but the conceptual understanding in discovering the role of assumptions and model development in driving those techniques to a valid solution and conclusion. The ability to recognize problems, formulate a mathematical model, use technology, and to communicate and reflect on one's work are important skills to develop. Applying the mathematical principles and concepts that one learns is key to individual and societal future success.

Awards

Finalist
Meritorious
Honorable Mention
Successful Participant

After final judging, MidMCM papers receive a designation in one of the categories above. Depending upon the quality of the papers, the top 20-25% of submitted papers receive a designation of Meritorious or above, with approximately the top 1-2% designated as Outstanding.

2025 Contest Dates

Mark your calendars for the 5th annual MidMCM, and the 28th HiMCM, to be held November 5–18, 2025. Registration for the 2025 MidMCM and HiMCM will open in September. Student teams may work at any time during the contest window. At the team members' convenience, teams download and choose their problem, complete their modeling solution, and electronically submit their solution document by the deadline on November 18th. Again in 2025, one team for each problem will receive the NCTM award. Teams can learn more about COMAP's contests and registration at:

https://www.comap.org

MathModels.org

Powered by COMAP content, MathModels.org is a wonderful resource for students and teachers to make mathematical modeling a year-round activity. This site includes past competition problems, exemplary solution papers, and judges' commentaries that can provide guidance for teams preparing to compete. Teachers and students may use the materials found on this site to enrich their classes and help prepare students for mathematical and interdisciplinary modeling contests. We encourage you to visit

www.mthmodels.org

Problem Discussion

We were once again extremely pleased with the submissions to the fourth annual MidMCM. The teams followed the guidance and submitted well-written and organized papers with appropriate mathematics, explanations, and diagrams.

Our MidMCM problem focused only on middle school/level mathematics so that it is accessible to middle school/level students. Teams that were most successful clearly communicated their process of building a model and the outcomes from their model. This is often best done when teams use middle school/level mathematics content that they understand and can fully explain. Creative approaches were also successful, as unique considerations of the problem illustrated diversity of thoughts and mathematics. Creativity was evident in assumptions, solutions, and in other recommendations to ensure the music artist of their choice could have a successful tour. Making clear assumptions that are well justified play an important role in the strongest papers. Papers are not as strong when teams attempt to use advanced tools and/or concepts found on the internet that they cannot fully explain. In particular, many teams this year chose to use the Analytic Hierarchy Process. None of the teams that did so provided an explanation of this technique that made the submission rise to the level of Meritorious or above.

The specific problem discussion below describes how teams addressed the requirements of the The Modeling Musical Tour problem. Following this section, we provide judges' comments about the solutions and presentations by breaking down the various parts of a submission. To view the complete problem statement, visit:

www.mathmodels.org
or
www.midmcm.org.

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Problem C: The Modeling Musical Tour

As Taylor Swift's The Eras Tour concluded, teams were asked to consider what makes a music artist's tour successful. We asked MidMCM teams to consider the different factors that contribute to maximizing profits, increasing fan exposure and the fan experience, and consider scheduling. Taylor Swift's tour had over 150 shows in over 50 venues and generated over $2 billion in revenue. The tour route, costs, and revenue were all key factors in the tour.

To help scaffold this problem for the middle school/level, the MidMCM problem asked participating teams to identify what factors go into concert touring, choose a musical performer, build a touring model for their chosen performer, and determine how effective the model is by comparing their model to prior tours and making a recommendation for a future tour. While many teams chose Taylor Swift, there was a large variety of other musical artists chosen by the teams including Jay Chou, Ed Sheeran, Phoenix Legend, Michael Jackson, Sabrina Carpenter, Eminem, and Beyoncé.

For their selected musical performer, teams were first asked to investigate a past tour to identify factors that should go into planning a tour. Strong features of solutions for this component of the problem included the conducting of research on the musical artist's past tour (or tours).

Teams were asked to create a model based on this research that could be used to analyze the success of the performer's past tour. Based on their research, teams defined relevant variables for use in their model. Many teams had multi-part models that took into account different components of a concert tour, such as identifying and sequencing venue locations, and maximizing profits for each venue. Once the teams had created their model, they tested it by evaluating the performer's past tour.

Teams were then asked to apply their model to develop and analyze a plan for a future tour for the performing artist. Many teams focused on this aspect of the problem and designed a comprehensive plan for a concert tour using their model.

Teams reported on their model solutions by drafting a 1- or 2-page letter to the musical performer they had selected to explain their models and provide their recommendations to the committee. Strong papers provided clear explanations of their models and presented the results of their models.

Judges saw many interesting papers in the fourth MidMCM. Teams presented a range of methodologies, from simple and straightforward to more complex, to respond to the requirements of this problem. Some teams had creative solutions, considering the "danceability" of songs to design a set list like **Team 15469** did in **Example 1**, writing a rap in their letter to Eminem like **Team 15659** did in **Example 2**, developing a "continents" tour concept like **Team 14988** did in **Example 3**, and planning a tour around Taylor Swift's #13 like **Team 16372** did in **Example 4**.

It seemed teams had fun developing their solutions and the judges were happy to see their creativity shining through.

Judges Discussion

In this section, we provide comments from the judges about the submissions received this year. We start with an overall perspective, and then address each required section of the submission. Excerpts from top rated papers (Meritorious and above) are provided at the end to serve as exemplars. Full versions of the Outstanding papers are available at **mathmodels.org**.

Overall

It is imperative that participants follow the contest rules posted on the website. The papers should be no more than 25 pages (the AI Report does not count towards this limit) and use at least 12-point font. Within the 25 pages, participants should include the introduction/executive summary, the solution that addresses all parts of the problem, provides a reference list, and include any appendices. The papers should be organized, focused, well written, and free from any school or student identifying information. The process of developing, testing, and revising the model should be clearly explained. Although background research may be helpful to developing the model, this information should only be briefly addressed in the paper. We strongly encourage all participants to use spelling and grammar checkers before submitting a paper. Participants from outside of the United States of America should ensure that all symbols in tables and graphs are in English.

Papers considered for Finalist and Outstanding typically use the headings provided in the problem. They initially summarize the problem. These papers then preview their paper with an organized Table of Contents. Assumptions with justifications are clearly stated. They then explain the development of their model and its solutions, apply their model, and support the results mathematically. The very best papers communicate their ideas clearly, include a sensitivity analysis, address the model's strengths and limitations, and finally, state their conclusions.

As we did for prior MidMCM competitions, we continued to offer students and teachers the following guidance to assist in organizing a problem solution submission for the second MidMCM.

Guidance for MidMCM

Solutions must be in PDF format and submitted in one PDF document. However, this does not preclude MidMCM teams from doing mathematics, graphs, tables, sketches, etc. by hand and including pictures of their work in the single PDF document submission. As students move to high school and the HiMCM, we expect that submissions will be typed. For the MidMCM, advisors may technically assist students in putting their solution components into one PDF format file for submission.

As with HiMCM, there is a 25-page limit for the submission document. This does not mean your solution must be 25 pages. A shorter submission is certainly acceptable. All portions of your submission (text, graphs, tables, charts, pictures, etc.) must be within **one** PDF document that is 25 pages or less. We accept partial solutions.

In general, a complete solution submission is organized as follows:

Executive Summary

Write this summary after you have done all your work. This one-page summary is Page #1 of your solution document. It provides an overview of your work and includes actual results.

Table of Contents

List the major items in your solution document to show the organization of your paper.

Introduction and Restatement of the Problem
Introduce the problem. Restate the problem and require- ments in your own words.

Assumptions with Justifications
State any assumptions you made to simplify and solve the problem and state why you made those assumptions.

Variable Definitions
Define any variables you use in your model and equations.

Presentation of Model and Solution
Ensure you address all requirements and describe what you are doing in solving the problem. Show and explain all your work. Use representations that help you tell the reader how you solved the problem (for example: equations, tables, graphs, pictures, etc.).

Analysis of Your Work
Address any strengths (good points) and limitations (weaknesses) of your model and solution.

Concluding Paragraph – End your solution paper with a final concluding paragraph that summarizes your results and/or makes recommendations for future work.

Reference List
List any sources that you used to solve the problem (for example, website pages, newspaper, or magazine articles, etc.) Following the Executive Summary, teams should provide some brief background, restate the problem, and perhaps provide a preview of the solution.

Executive Summary

As the first page, or cover sheet, the Executive Summary provides a first impression of your paper. It should clearly and concisely communicate a synopsis of the paper, your modeling and analysis process, as well as your solution. Thorough, well-written descriptions of the problem and process are common. It is also important to include your actual results and recommendations. The Executive Summary should summarize the entire contents of the paper. Although typically written last, spend time on this important part of your submission.

Introduction/Background

Following the Executive Summary, teams should provide some brief background, restate the problem, and perhaps provide a preview of the solution. They should not simply repeat what was in the summary. Most teams this year limited their background to a restatement of the problem. For this problem, **Team 15453** impressed judges with a list of inquiry questions they developed to guide their exploration of past tours **(Example 5)**.

Assumptions with Justifications

Good models make necessary assumptions to help simplify the modeling process. These are sometimes called simplifying assumptions. A common mistake that judges see is teams making assumptions that are not needed nor relevant to developing their model. Good and relevant assumptions are difficult to identify and articulate. You should include a short justification to show each assumption is reasonable and explain why it is necessary for the construction of the model. **Team 16255 (Example 6)** offered 12 assumptions. Despite the number of assumptions, the list was not so long that it detracted from the modeling. This effect is due to the team's use of all these assumptions in their model, making them all truly necessary, and the thorough justification of each which contributes greatly to the length of the section. The judges encourage teams to be discerning in their choices of assumptions.

Definition and Use of Variables

Most mathematical models include several (and sometimes many) variables that teams must define for the reader. This list of variables should include the variable symbol, a short description of the variable, and the units of the variable. Using best practices, teams should focus on a manageable set of variables when modeling. Variables with descriptive subscripts can help with readability. Additionally, as you use variables in your model, remind the reader of the variable definitions and units. This practice assists the reader in following the logic of your process. A nice list of descriptive variables is shown in **Team 16009's** variable definitions in **Example 7**.

Mathematical Model

The development of the mathematical model is the most important part of your submission. There is always more than one appropriate solution method to each MidMCM problem and so teams should address the problem with the mathematics they know and understand. Papers should explain the development of the mathematical model(s) and/or algorithm(s) and define the relationships between variables in a logical manner. Teams should take the reader on a journey when describing their thought process and steps. Teams who succeed will explain why they choose their model and how they plan to use or modify it to fit this problem. Judges are more impressed with a well thought out (and perhaps simple) model than with a very complex model that a team struggles to apply or explain clearly. To impress the judges, focus on applying sound principles to your model that you understand. While judges do value creativity and thinking "outside of the box" in your modeling process, be sure to balance creativity with your level of expertise and modeling experience. So, be creative and have fun.

Both Outstanding teams developed models that impressed the judges. **Team 15637 (Example 8)** used a simplistic approach with limited assumptions. While the model would need to be revised, the assumptions simplified the team's approach to develop a mathematical model to address the problem. **Team 15712 (Example 9)** also impressed the judges with their explanation of the initial model, revisions, and the final model they developed for this problem. There are many ways to model and analyze the MidMCM problem. This year we saw a variety of appropriate, as well as creative, models. Many times, a picture is worth a thousand words! The use of tables, graphs, and images is often helpful to show your modeling process.

The Letter

The purpose of the letter is to show the judges that regardless of the complexity of your mathematics or analysis, you can convey your work and solution in common terms. Often, the recipients and consumers of mathematical modeling and research are not as technically astute as the mathematicians and scientists doing the work. In writing the letter, teams must translate their hard work into a shorter descriptive format. This increases the likelihood your audience will understand and consider your solution and recommendations.

Like the executive summary, the letter briefly describes the problem and the background, your model or process, and your results as well as any recommendations. Some teams include visuals in their letter. These graphics can assist the team in presenting their process and the reader in understanding the model and results. **Team 15637** provides a clear and well written letter explaining the considerations and results of their model to Justin Bieber **(Example 10)**. Similarly, **Team 16255** clearly explained that they used their model to evaluate multiple possible tour plans for Taylor Swift **(Example 11)**.

Additional Details

Other considerations are also important. For example, **Team 15366's (Example 12)** writing style was accessible. It is important to be thorough, but also communicate the model as simply as possible.

Sometimes teams go beyond the requirements of the problem in a way that shows that they are thinking deeply about the problem. These details are always appreciated by judges when they come in addition to, and not at the expense of, the problem requirements.

Strengths and Limitations

As teams only have a short time to develop their solutions, they should be critical of the approaches and mathematics they used in their solution. Teams should identify strengths and limitations of their work, by asking questions such as: Is your solution reasonable? Under what conditions will it perform best and where will it not? Additionally, teams should address how changes might impact their solution. Was there a critical assumption made that if changed would significantly change the solution? Would changing the values of any constants or multipliers (coefficients) significantly impact your results? Teams should validate their models, even if by numerical example or intuition.

Sensitivity Analysis

Few teams included a sensitivity analysis, which is an exploration of the impact of an assumption by changing it in some way. For instance, **Example 13** shows **Team 16009's** sensitivity analysis for their model where they explored the impact of changing the value of their variables by 10%, 20%, and 30% in each direction.

Reflection

The purpose of the reflection part of this problem that asked teams to examine if their model could be used to design a tour for another performer was to have teams think about the adaptability of their model. Few teams discussed this in detail. The few that did, acknowledged that a performer's popularity or the desired geography of the tour may play a role in how generalizable the model is. **Example 14** is from **Team 15478** who identified that parameters in their model could be adjusted to be applied to other performers.

Conclusion

A clear conclusion and answers to the specific scenario questions are key components to an Outstanding paper. Attention to detail and proofreading your paper prior to final submission are vital as the judges look for excellence in your submission. Teams should take the time to read the entire paper to ensure they have followed a logical sequence and flow that tells a story from start to end. Few teams included a conclusion like this, but it was appreciated when it was a meaningful reflection on their work, complete with ideas for the future.

Citations and References

Citations are very important within the paper, as well as either a reference list or bibliography page at the end. Teams that use existing models should cite their source(s) within the paper at the point they present the model and include a reference citation in the back of the paper. This is also true for all graphs and tables taken from the literature. Use "in line" documentation with footnotes or endnotes to give proper credit to outside sources. All data, figures, graphs, and tables that come from outside sources require documentation at the point in the paper where they appear. Lack of documentation will result in a lower designation. Judges have noticed many teams use Wikipedia as a source. While Wikipedia can be a great tool for learning about something rather quickly, it is not an academic source and as such should not be trusted as a sole source. Teams should look for and use more authoritative – ideally primary sources – whenever possible.

AI Usage Report

Teams are required to include a declaration of how they use AI if they use generative AI tools as part of their process. Teams have used AI for multiple purposes including to quickly collect data sets from online sources, to examine coding libraries to better understand how code can be used, and to generate potential strategies to be used. It can be a helpful tool for students, but all uses need to be documented. The AI use report is not included in the 25-page limit.

Final Thoughts

The submissions for the fourth year of the MidMCM impressed judges and left them excited for the future of modeling. We truly enjoy reading all solution papers. We hope all participating students also enjoyed the experience and improved their mathematics, modeling, and communication skills in the process. We encourage students of all levels to compete in future MidMCM competitions. To be successful, read the comments and guidance provided in this article, see the HiMCM and MidMCM Resource Guides on the contest Instructions page of the COMAP website, and visit mathmodels.org to review previous problems.

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information.

List of Examples

1. Creative Solutions (Team 15469)
Shanghai Starriver Bilingual School, China

2. Creative Solutions (Team 15659)
Shanghai Starriver Bilingual School, China

3. Creative Solutions (Team 14988)
Huawei, China

4. Creative Solutions (Team 16372)
RCF Experimental School, China

5. Intro/Background (Team 15453)
Duniway Middle School, OR, USA

6. Assumptions (Team 16255)
R.J. Grey Junior High, MA, USA

7. Variables (Team 16009)
Scarsdale Middle School, NY, USA

8. Model Development (Team 15637)
Shanghai Starriver Bilingual School, China

9. Model Development (Team 15712)
Shanghai Starriver Bilingual School, China

10. Letter (Team 15637)
Shanghai Starriver Bilingual School, China

11. Letter (Team 16255)
R.J. Grey Junior High, MA, USA

12. Additional Detail (Team 15366)
Rye Country Day School, NY, USA

13. Sensitivity Analysis (Team 16009)
Scarsdale Middle School, NY, USA

14. Reflection (Team 15478)
Jiashan Experimental School
Affiliated to Shanghai University, China

The *Ed Sheeran Spotify Dataset* consists of a table with 272 rows and 17 columns. Every row is a song and the columns are the separate data for the song, respectively the **name, album, release date, track number, Spotify id, Spotify URI, acousticness, danceability, energy, instrumentalness, liveness, loudness, speechiness, tempo, valence, popularity, and duration(ms)**. For example, the top 5 rows in the chart include data like:

name name of song	acousticness amount of acoustic in the song	danceability how suitable the song is to dancing	energy the amount of intensity and activity in the song	instrumentalness amount of no vocals in the song
One 1% I'm a Mess 1% Other (266) 98%	0 0.95	0.32 0.96	0.09 0.92	0 0.71
One	0.877	0.467	0.321	0.0
I'm a Mess	0.56	0.697	0.379	0.0
Sing	0.3	0.818	0.67	1.13e-06
Don't	0.0113	0.807	0.608	0.0
Nina	0.175	0.791	0.67	0.0
Photograph	0.607	0.718	0.379	0.000472
Bloodstream	0.528	0.66	0.315	0.000298
Tenerife Sea	0.7	0.526	0.345	1.13e-05
Runaway	0.024	0.767	0.449	0.000283
The Man	0.576	0.76	0.724	0.0
Thinking out Loud	0.474	0.781	0.445	0.0
Afire Love	0.465	0.552	0.635	1.62e-05

Figure 2: Some Columns of the Dataset

F. Letter to Eminem

Dear Eminem:

I hope this letter reaches you well. Here is a rap version of our letter.

Have fun reading!

I'm writing with respect, not tryna offend,
You're a legend in the game, we all comprehend.
But lately, my guy, it's a little lacklustre,
Where's the fire, the grit, that lyrical cluster?

Now let me introduce what's working right here,
Our model's spitting lines that are smooth and sincere.
Quick on the beat, with precision that's tight,
Droppin' bars and insight, day or night.

Not claiming the throne, you're the rap god, true,
But we're bringing fresh rhythm, adding something new.
Constructive vibes, not dissin' for the clout,
Just hoping the next track brings the beast back out.

Our model should effectively help you plan next performance well; our team believes that it would be useful for you to acknowledge it overall. Your songs are enjoyable, but you have further improvement to go on budgeting and planning.

I hope that our mathematical model can help you increase your overall profit and decrease costs and better disperse your budget, by utilizing them in a more appropriate way. I hope this is practical to you.

INVARIANTS
2024.11.18

Example 2. Creative Solutions (Team 15659)
Shanghai Starriver Bilingual School, China

We would provide a simulation. There will be seven stops on the tour and each stop would have a separated bill of materials and a bill of profits. The seven stops are: **New York City--> Rio De Janeiro --> Pretoria->Paris-->Hong Kong -->Sydney-->Antarctica**

3.3. Antarctica

Population Size Estimate:

- Antarctica doesn't have a population, so we will assume a very niche audience. Let's say only 1,000 tourists and researchers are attending the event (it's more symbolic).

Example 3. Creative Solutions (Team 14988)
Huawei, China

5. Symbolic Dates (e.g., the Number 13) Will Enhance Fan Experience
   - Assumption: Fans will value performances scheduled on dates associated with Taylor Swift's brand, such as the 13th of each month.
   - Justification: Taylor's fans are highly engaged with her personal symbols, and such dates can create added excitement and marketing buzz.

Example 4. Creative Solutions (Team 16372)
RCF Experimental School, China

3. Introduction

3.1 Background

Taylor Allison Swift, one of the best artists of all time, is currently on the home stretch of her record-breaking Eras Tour. This is Swift's sixth tour, although it is the first that has reached $1 billion status; breaking an all time record for the highest grossing tour. She has amassed over 130 shows already and still has a bit more to go. This has blown the media away as this show is expected to make a whopping $1.4 billion dollars! This will make the second place tour, Music of the Spheres by Coldplay stand above 1 billion also, as it has just surpassed this benchmark.

Although the Eras tour is the most current news, her past shows have additionally showcased Taylor's growth as a musician and performer. Starting with her country background on the Fearless tour in 2009, Swift evolved to more of a pop artist in 2015 with her 1989 world tour. Today, Swift blends a variety of music styles and tastes, solidifying her status as a global icon.

Swift mainly revolves around love and relationship themed songs. Though centered around English lyrics, Taylor Swift manages to attract fans from all over the world. On the 9th of November, the "Swifties" had grown to 90.4 million active listeners. This makes Taylor one of the most popular artists right now, and she has been for the past 15 years. However, Taylor isn't just doing it for the fans, she's also using her lyrics to express her emotions and feelings.

3.2 Restatement of the Problem

In this problem, we were tasked with determining a possible plan for a future tour of Taylor Swift, ensuring a smooth running and high energy experience. However, we should plan it out so that the tours aren't too short, nor too long. We must consider all situations and mishaps that could occur during the whole tour. With all consideration of these scenarios, we are asked to create a model on what the tour would look like and how they would profit off of it. Then, we include all the necessary information such as venues and time management, and finally, write a letter to Swift herself regarding our model and why she should use it for her next tour.

Example 5. Intro/Background (Team 15453)
Duniway Middle School, OR, USA

Based on the careful review of the past 5 tours, we will carry out the modeling process with the **Assumptions** below:

1. Assumption: Taylor Swift's goals for this tour include maximizing profit and public figure/popularity.

   Justification: Our model assumes that the optimization goal of this tour is to maximize profit and Taylor Swift's public figure. Based on her explanations for starting past tours, we know Taylor Swift usually starts tours to increase her popularity and meet with fans around the world. The trend we observed also clearly supports this assumption.

2. Assumption: The number of tickets sold in each concert will be a constant percentage of the venue capacity, and the constant we used is 78.41%.

   Justification: Concert tickets are sold out very early once available to the public, and there are certain numbers of seats reserved not for sale. The average attendance of each concert in the Reputation tour is 78.41% [8][9][10][11][12][14].

3. Assumption: Slightly adjusting the ticket price won't influence the attendance.

   Justification: Many Taylor Swift fans try extremely hard to get tickets for her concerts before they sell out, as she is really popular, and the tickets sell out quickly. Therefore, a fan wouldn't not purchase the ticket just because of a slight increase in the price. In addition, even if some fans decide not to purchase a ticket because of changes in the price, Taylor Swift's concerts have waitlists of up to 2 Million people waiting for tickets [15], so we assume that her concerts will always be full and adjusting the ticket price slightly won't change the attendance.

4. Assumption: Lodging and transportation costs can be ignored, and crew costs and venue costs don't have fixed prices, but rather cut off a percentage of the total revenue, so the cost doesn't impact the final optimization result when different models are compared.

   Justification: When Taylor Swift performs a show, she has to pay for many different things. Renting a venue and paying her crew make up a large portion of this total cost, which may be contracted as a percentage of the total revenue, whereas lodging and transportation costs are very little in comparison. Using The Eras Tour as an example, the total transportation cost of production equipment, stage, lighting, costumes, instruments and everything else is around $15M USD, which is 1.5% of the total revenue [16].

5. Assumption: Taylor Swift wants to include as many cities as possible in one tour.

   Justification: Including more geographic regions in a tour can increase Taylor Swift's popularity around the world because she is introducing herself to other cultures that may not be as familiar with Western music.

Example 6. Assumptions (Team 16255)
R.J. Grey Junior High, MA, USA

6. Assumption: Taylor Swift would still want to go to countries where she is very popular and where her past shows have been successful. Such areas include, but are not limited to, North America, Europe, and Oceania.

   Justification: If Taylor Swift has been very successful in these areas, she should go there again not only to maximize the amount of profit she could earn, but also to ensure that her biggest fan bases in English-speaking/Western culture countries are included in her tour.

7. Assumption: Including new cities in her tour helps promote Taylor Swift's public figure/popularity.

   Justification: Online information demonstrates she has a lot of fans among non-English-Speaking countries. Reference [17] shows that Taylor Swift is the most translated artist in the world.

8. Assumption: If we divide the tour length by the number of shows, we get the number of days between two separate shows.

   Justification: Taylor Swift needs a couple of days between shows to rest and set up for the next show, so this amount affects the quality of her shows. Therefore, we don't want this number to be too low.

9. Assumption: The planned tour will be no longer than 200 days.

   Justification: we are trying to use our model to compare it with the Reputation Stadium Tour, so we must make the durations similar, so they are comparable.

10. Assumption: We calculate the total revenue using the average ticket prices of shows and still get accurate results.

    Justification: A concert could have a very wide range of ticket prices, ranging from less than $100 to $10,000+ [18] and it would be too complicated to calculate all the different ticket prices and wouldn't give us extra benefits in calculating the revenue of each show.

11. Assumption: We will use the historically highest average ticket price to predict the total revenue for the tour we are planning, at the cities she has visited before. For new cities she had never toured before, we estimate the ticket price referencing cities in the same continent.

    Justification: According to Assumption 3, a price estimation is reasonable if tickets had been sold at the same price before. (Average ticket prices are calculated based on information in [8][9][10][11][12].)

12. Assumption: In each city on the tour, there will be a venue with large capacity available to maximize the total revenue.

    Justification: Taylor Swift has global influence and with planning ahead early enough, the major venue will be accessible to such impactful events.

Example 6. Assumptions, Continued (Team 16255)
R.J. Grey Junior High, MA, USA

IV. Variable Definitions

Factors we considered in order to run a single show and the a tour are:

C_{Venue}	Average Venue Capacity (number of seats)
P_{Ticket}	Price of Tickets (USD)
$A_{Attendance}$	Expected Attendance (percentage)
N_{Shows}	Number of Shows
C_{Travel}	Travel & Logistics Cost (USD)
C_{Other}	Other Costs (stage crew and other staff) (USD)
$C_{VenueCost}$	Average Venue Cost per Show (USD)
$C_{Security}$	Security Cost per Show (USD)
O_{Opener}	Opener's Pay ($15,000) (USD)
R_{Merch}	Average Merch Revenue per Attendee (USD)
$C_{StageEffects}$	Cost of Stage Effects per show (USD)

Example 7. Variables (Team 16009)
Scarsdale Middle School, NY, USA

To open a tour, many factors, such as fan attendance, the GDP of a concert location, or ticket prices, need to be considered [6, 7]. To determine the best locations for opening Bieber's concerts, a model can be built to decide on the preferable range of the ticket prices of each concert, and the GDP of the cities where said concerts are held.

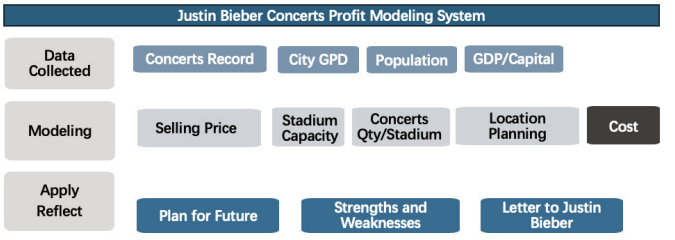

Figure 1. Schematic diagram of Justin Bieber concerts profit modeling system.

We analyzed different data about Justin Bieber's past tours [8]. Since the Purpose World Tour is the tour that Justin Bieber made the most money and our goal is to maximize the profit of our tour, most of our references to past data will be about the **Purpose World Tour**.

Example 8. Model Development (Team 15637)
Shanghai Starriver Bilingual School, China

3 Developing a Model

3.1 Our Initial Model

We initially made use of the variables that we had carefully defined to establish a straightforward relation. This relation included several key elements including profit, the number of tickets sold, ticket price, the rent and the maintenance fees within the context of one concert and profit derived from peripherals. In this model, we were aiming to clearly demonstrate how these factors interacted with one another: $x = at - r - c$

This relation was designed to show how the profit was calculated. It was determined by multiplying the ticket price by the number of tickets sold. However, this was not the final figure as we then had to subtract the costs associated with putting on that one specific concert. This cost factor considered various parameters such as venue rental, artist fees, staff payments, and any other expenses related to the production of the concert. By subtracting these costs from the revenue generated by ticket sales (which was calculated by multiplying the ticket price and the number of tickets sold), we arrived at the profit value for that concert event.

4. Final Model

This is our final model:

$$x = \Sigma_{i=1}^{n}[0.2322\% \cdot p_i \cdot a_i \cdot (1 - y_i) - r_i - c_i](1 + 0.0428\% \cdot g - 30\%)$$

We included the cities and every city's profits from every concert. In this final model, i represents the cities (labeled). Also, we included the merchandise in our profit.

7 A Letter to Justin Bieber

Dear Justin,

We hope this letter finds you well. As your tour managers at MidMCM Music Agency, we are excited to present a comprehensive tour model that we have developed to optimize your upcoming concert tour. Our team has analyzed your past tours and identified key factors that contribute to a successful and profitable tour. We believe that our model will not only meet but exceed your goals for fan engagement and financial success.

Our Approach:

• Familiarization with your **touring history**.

• We began by examining your previous tours, focusing on the reasons behind your tours, duration, number of shows, and locations. This analysis provided us with a solid foundation to understand your touring patterns and fan base.

• Identifying key factors

• We considered various factors that impact a single show and the overall tour, including **logistics, venue capacity, ticket pricing, and promotional strategies**.

Model development

• Our model incorporates a dynamic approach to planning, taking into account the number of concerts, selection of venues, and ticket pricing strategies. We have also integrated a module to predict fan attendance based on historical data and market trends.

Maximizing Goals

• We have designed the model to help achieve various objectives, such as **maximizing fan attendance and optimizing profits**. The model suggests strategies tailored to your specific goals and the unique dynamics of each tour.

Our Recommendations:

• City Selection: Based on our analysis, we recommend **targeting cities with a high concentration of your fan base** and a track record of successful past shows. We separated the cities into the **3 tiers**: tier 3 cities will hold 3 concerts, tier 2 cities will hold 2 concerts, tier 1 cities will hold one concert. After using our model, we concluded that in 130 concerts, there are **13** concerts held in a tier 1 city, **26** concerts in a tier 2 city, and **91** concerts in a tier 1 city, which shows that there will be **108** host cities.

• Ticket Pricing: To maximize both attendance and revenue, we propose that the best value for **ticket price is $90**.

Why This Tour Will Be a Success:

Example 10. Letter (Team 15637)
Shanghai Starriver Bilingual School, China

Our model predicts that by following these recommendations, the profit of your tour before subtracting the cost (such as your transportation, venue price, and staff) of the concert is **$502,320,000**. The tour will not only be **financially successful** but also create **lasting memories** for your fans. We believe this approach will enhance your brand, expand your reach, and solidify your position as a top-tier performer in the music industry.

Looking Forward:

We are eager to discuss this model in more detail and tailor it to your specific needs and vision for the tour. We believe that with this strategic approach, your upcoming tour will be your most successful yet. Please feel free to reach out to us with any questions or to schedule a meeting to further discuss the details. Thank you for entrusting MidMCM Music Agency with this exciting opportunity.

Sincerely,
Our team,
#15637

Example 10. Letter, Continued (Team 15637)
Shanghai Starriver Bilingual School, China

6. Letter to Musical Performer

Dear Taylor Swift,

This is your team at the MidMCM Music Agency. Thank you so much for hiring us, as we are delighted to be given the opportunity to help you plan out your next tour. Based on your past tours, we have developed a model and utilized the model to create a concert tour plan, which we think will work best for you. We took many things into consideration, such as venue prices, ticket prices, and countries that you are thought of as the most popular. From looking at some research about reasons you started tours in the past (these include meeting with fans, promoting your albums, spreading popularity, and having the tour be profitable), we've made an assumption that your goals for this tour include maximizing the profit made and increasing your popularity around the world.

After conducting the necessary research about your past tours—primarily focusing on your Reputation Stadium Tour to compare it to our plans—we developed a list of 38 city candidates that we would consider adding to our plans. These cities include new cities that you have never visited before, cities in emerging areas, and large cities in regions you have visited. Visiting new cities and cities in emerging areas is important for our plans because it helps increase your popularity in regions that you might not have ever toured in.

We are trying to set up a tour that is comparable to your latest past tour, the Reputation Stadium Tour (we are not counting the Eras Tour as a "past tour", as it is still ongoing), which was held for 197 days, so we have set your next tour as 200 days. We want to stay in each of our cities for 2 different shows since we picked relatively large cities and their biggest venues. Our research shows us that the average number of days between each one of your shows in a tour is 3.93, so we round this up and give 4 days between shows for rest time, travel time, leisure time, and set-up time. Finally, after doing the math, we know that we are visiting 25 different cities, holding 50 shows total (2 shows at each city), and having 4 days between each show, which amounts to 200 days total for this show, as desired.

Next, we made 6 different combinations of 25 cities from our city candidate list and named them Plan 1 through Plan 6. The reason we created 6 different plans was that we wanted to see if the tour outcome is more dependent on the total revenue, or popularity. For each plan, we calculated the total revenue and counted the total amount of new and emerging cities visited. Using these values, we developed a Performance Index (*PI*) for each plan and compared them, the higher the value, the better. So, changing the amounts of new and emerging cities in each plan can help us see if popularity or revenue plays a bigger role in our *PI* calculation. This is because a city in an emerging area might require smaller venue sizes, which lowers the total revenue. On the other hand, including an emerging city will undoubtedly boost your popularity.

In our 6 plans, from Plan 1 to Plan 6, we are gradually including more new and emerging cities in our list of 25 cities visited. For example, in our Plan 1, we have 1 new city and no emerging cities,

Example 11. Letter (Team 16255)
R.J. Grey Junior High, MA, USA

whereas in Plan 6, we have 5 new cities and 8 emerging cities. Next, we calculated the *PI* for each of these plans and found that the *PI* for Plan 6 was higher than any of the other plans which included less new and emerging cities. We also compared these *PI* values with the *PI* value for your Reputation Stadium Tour, and found that ours were larger, most likely because we included more cities in emerging areas and used bigger venues as often as possible.

In conclusion, Plan 6 had the best results, and it would be recommended that you visit the cities included in Plan 6 for your next tour.

We hope you will consider using our plan,

Team #16255

Example 11. Letter, Continued (Team 16255)
R.J. Grey Junior High, MA, USA

Model 1: Maximizing revenue

Since there were 60 days of concerts in the North American leg, we will work with the same number of days. Assuming 4 performances per city, we will pick the top 15 cities that generated the most revenue. These cities were Las Vegas, Fargo, Saint Paul, Auburn Hills, Chicago, Toronto, Louisville, New York City, Washington, D.C., Brooklyn, Philadelphia, Sunrise, Miami, Oakland, and Inglewood. The total revenue that we projected these 15 cities to amass would be $119,258,300, or an **11.9% increase** in revenue in comparison to the original revenue from the 24K Magic tour.

Model 2: Maximizing fan attendance

Based on the same information from the 24K Magic tour above, we selected the top 15 cities that had the highest fan attendance. These cities were Las Vegas, Tacoma, Fargo, Saint Paul, Auburn Hills, Cleveland, Chicago, Toronto, Montreal, Charlotte, Louisville, Buffalo, Washington, D.C., Philadelphia, and Oakland. Spending four nights in each city means the total projected fan attendance would be 1,008,572, a **10.3% increase** compared to the 24K Magic tour.

Model 2 Extension

To further maximize fan attendance, we can include larger venues that were not used during the 24K Magic tour but hold more people. This includes iconic stadiums that are well-known and can usually hold upwards of 50,000 people. This will allow for plenty of space for fans but may cost more to rent. Some locations include Met Life Stadium in New Jersey, Levi's Stadium in California, Rose Bowl Stadium in California, Lumen Field in Washington, and Hard Rock Stadium in Florida. The concert capacities of these venues are listed below. If we replaced the concerts with similar locations to these venues, we project a **32.6% increase** in fan attendance from our original model, and a **46.3% increase** in fan attendance from the 24K Magic tour, assuming Bruno Mars keeps his sellout rate.

1. Met Life Stadium - 60,000 people
2. Levi's Stadium - 50,000 people
3. Rose Bowl - 70,000 people
4. Lumen Field - 55,000 people
5. Hard Rock Stadium - 50,000 people

5.3 Total Cost Breakdown

Total stage setup costs for each show include expenses like visual effects, props, screens, and speakers. The total cost for stage setup would be around $180,000 per show, assuming it costs around 10% of concert revenue. Our model reduces total costs because instead of setting up 46 different venues, we were able to cut it down to only 15 venues. Additionally, we will save on air

Example 12. Additional Detail (Team 15366)
Rye Country Day School, NY, USA

travel and shipping expenses, because there are fewer stops. We were able to come up with an estimate based on the following generalized information:

Air Travel

- Private Jet Rental
  - Hourly Rate: $5,000 per flight hour for a mid-sized to large jet
  - Assuming two-hour flights between cities
- Commercial Flights for Crew
  - Average Flight Cost: $500 per two-hour domestic flight
  - Assuming 30 crew members

Stage Setup Cost

- About 10% of the revenue of one concert per city [5]

To summarize the amount that would be saved from only going to 15 venues, we organized the values into the table below:

Category	Amount Saved
Air Travel	Reduced from $1,150,000 to $375,000, saving $775,000
Stage Setup Cost	Reduced from $8,280,000 to $2,700,000, saving $5,580,000
Total Saved	$6,355,000

Example 12. Additional Detail, Continued (Team 15366)
Rye Country Day School, NY, USA

We ran a sensitivity analysis, for the profits as shown below.

Parameter	Decrease by 30%	Decrease by 20%	Decrease by 10%	Base Value	Increase by 10%	Increase by 20%	Increase by 30%
Average Venue Capacity	$87,104,600.00	$101,387,600.00	$117,184,600.00	$135,982,000.00	$156,177,400.00	$179,371,600.00	$204,565,000.00
Ticket Price	$81,882,200.00	$99,782,200.00	$117,882,200.00	$135,982,000.00	$154,081,800.00	$172,181,800.00	$190,281,800.00
Expected Attendance	$64,135,200.00	$88,335,200.00	$111,135,200.00	$135,982,000.00	$161,335,200.00	$186,135,200.00	$211,135,200.00
Number of Shows	$97,935,200.00	$111,787,000.00	$124,964,000.00	$135,982,000.00	$164,018,000.00	$164,018,000.00	$178,036,000.00
Average Merchandise Revenue	$114,982,000.00	$123,982,000.00	$129,982,000.00	$135,982,000.00	$147,982,000.00	$147,982,000.00	$153,982,000.00

Example 13. Sensitivity Analysis (Team 16009)
Scarsdale Middle School, NY, USA

7. Reflect

Our model can help plan another music performer's tour by first collecting data related to the performer, such as venue rent, fixed costs, estimated ticket sales, and transportation distance between cities, to calculate the profit that each city tour can bring as input to the model. Then, a 0-1 integer programming model is used to select the optimal tour cities and their order, in order to achieve maximum profit. On this basis, the shortest path algorithm is used to optimize the tour sequence between cities, reducing transportation costs and time. This model is not only applicable to a single performer, but can also be customized and adjusted according to the needs of different performers. For example, some performers may focus on specific markets or increasing box office revenue, while other performers may be more focused on reducing costs or shortening tour cycles. Therefore, by adjusting the parameters in the model, customized tour plans can be provided for different performers to meet their unique goals and needs.

Example 14. Reflection (Team 15478)
Jiashan Experimental School Affiliated to Shanghai University, China