Striking Out Excess Travel In Major League Baseball: Reducing CO2 Emissions Due To the MLB Schedule

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ABSTRACT

Air travel has several negative environmental effects, including CO2 emissions, which contribute to global climate change. To counteract the emissions that will result from an anticipated increase in air travel demand, organizations and individuals can eliminate unnecessary air travel. Major League Baseball (MLB) teams must travel a great deal to complete the 162-game schedule. Optimizing the MLB schedule to minimize travel could eliminate significant amounts of CO2 emissions. I sought to estimate by how much MLB could reduce its carbon footprint through optimizing travel for one MLB team, the Chicago Cubs. The Traveling Salesperson Problem (TSP) is a classic optimization problem in which a traveling salesperson must find the shortest route that visits *n* number of cities and returns him home. To minimize the CO2 emissions associated with alternative travel scheduling rules, I built a TSP-type optimization model in Microsoft Excel using the Solver add-in. I identified scheduling constraints by studying the official schedules of several teams and by reading the MLB 2012 Basic Agreement. I compared the CO2 emissions from the Cubs' official schedule to the emissions generated by the optimized schedule. I found that CO2 emissions can be reduced by 4.7% while satisfying all constraints. I also found that, in the case of the 2014 Chicago Cubs, interleague play reduced total emissions. While my model is not indicative of all of MLB, it indicates that, in the case of the Cubs, changes to the way the MLB schedule is created can reduce CO2 emissions.

KEYWORDS

Scheduling, optimization, baseball, traveling salesperson problem, Excel Solver

INTRODUCTION

Air travel has several negative environmental effects such as CO2 emissions, which contribute to global climate change (Jardine 2005). In 2013, the global airline industry consumed 1.74 billion gallons of fuel and emitted 700 million tons of CO2 (IATA 2014); for comparison, the average American is responsible for 19 tons of CO2 annually (Rosenthal 2013). Both fuel consumption and CO2 emissions have risen steadily in the airline industry over the last decade (IATA 2014) and will likely continue to rise. Airlines expect a 31% increase in passenger demand by 2017 (IATA 2013). And Boeing expects the number of planes it has in the skies to increase from 20,910 to 42,180 by 2033 (Boeing 2014). Because fuel represents 30% of operating costs for airlines, market forces incentivize airlines to minimize fuel consumption and pursue fuel efficient fleets (Holland et al. 2011).

It has been estimated that aircraft fuel efficiency can be improved by up to 50% by 2050 (Khan Ribeiro et al. 2007). Airbus completed a flight which achieved 40% reduction in fuel burn compared to other flights taking the same route (Airbus 2012). While alternative fuels such as liquid hydrogen and bio-diesel can further reduce CO2 emissions, the airline industry is likely to depend on fossil fuels for the foreseeable future (Khan Ribeiro et al. 2007). Therefore, a short term strategy is required to reduce CO2 emissions due to air travel while fuel-efficient technology and alternative fuels are developed. To counteract the emissions that will result from the expected 31% increase in passenger demand, organizations and individuals must eliminate unnecessary air travel.

Major League Baseball (MLB) teams must travel a great deal to complete their 162-game regular season schedule. The Chicago Cubs, for example, traveled over 36,600 km in 2014. For 6 months, teams travel across the country to determine which teams will play in the postseason (MLB and MLBPA 2012). A complete schedule for a team from New York, for example, involves multiple trips to the Southwest, Northwest, Midwest, and south Florida. Due to the compact nature of the schedule, there are not many days off. Teams must often be on the West Coast the day after a game on the East Coast or vice versa. Due to need to quickly travel from city to city the preferred method of transportation for MLB teams is air travel. A flight from New York to Los Angeles, which is made multiple times a season by MLB teams, produces over 2 tons of CO2 (Jardine 2005). Therefore, MLB is a substantial contributor to climate change because of its air-travel-intensive schedule. Optimizing the MLB regular season schedule to minimize travel could eliminate significant amounts of CO_2 emissions.

My project sought to optimize travel for the MLB regular season schedule in order to reduce CO_2 emissions for one MLB team, the Chicago Cubs. My central research question was: By how much could the Cubs reduce its carbon footprint by optimizing its schedule with respect to air travel? To answer this question I determined the distance traveled by Cubs for the 2014 MLB regular season and then quantified the CO_2 emissions due to the Cubs' air travel. I identified key constraints of the MLB regular season schedule. I then used an Excel model that accounted for the identified constraints to optimize the Cubs' schedule for CO_2 emissions. Constraints were either imposed or removed to determine how the schedule changed with different scheduling requirements. A schedule feature of particular interest was interleague play wherein teams from the American League (AL) play teams from the National League (NL). Every season each of the NL diveisions (East, Central, and West) is paired with one of the AL divisions (East, Central, and West) on a rotating basis.

METHODS

Study system

The study system for my project was the MLB regular season schedule. The schedule consists of 162 games split into 52 segments for each of the 30 teams in MLB. A great deal of air travel is required to play all of the games on the schedule, which produces large amounts of CO_2 emissions. For 8 months, teams travel across the country to determine which teams will play in the postseason (MLB and MLBPA 2012). A complete schedule for a team from New York, for example, involves multiple trips to the Southwest, Northwest, Midwest, and south Florida. Due to the compact nature of the schedule, there are not many days off. Teams must often be on the West Coast the day after a game on the East Coast or vice versa. Due to the need to quickly travel from city to city the preferred method of transportation for MLB teams is air travel. If the travel schedule were optimized significant CO_2 emissions could be avoided. In particular, my project was concerned with the 2014 regular season schedule of the Chicago Cubs.

Data collection

The Traveling Salesperson Problem (TSP) is a classic optimization problem in which a traveling salesperson must find the shortest route that visits *n* number of cities and returns him home (Ragsdale 2010). While it is simple in concept, the TSP becomes incredibly complex when constraints are introduced. Optimizing the MLB schedule to reduce travel is a TSP with many constraints because there are many requirements that the MLB schedule must satisfy, including a limit to the number of consecutive home or away games, and a required number of games against divisional opponents (MLB and MLBPA 2012). Other industries have done extensive research regarding TSPs in order to maximize efficiency (Wohlsen 2013). However, MLB is not one such industry, and there is little literature regarding optimizing travel for professional sports.

The amount of CO2 emissions generated by the Cubs due to its 2014 travel schedule was the baseline to which I wanted to compare the emissions figures generated by my model. I calculated the emissions generated by the Cubs' official 2014 regular season schedule and I used the same methods to calculate emissions between cities for my model.

To calculate the CO2 emissions associated with alternative travel schedules, I built a TSP-type optimization model similar to one built by (Ragsdale 2010). I built the model in Microsoft Excel 2010 using the Solver pack. Counting cities that have multiple MLB teams as separate destinations, the Cubs played in 19 different locations (including Chicago) during the 2014 MLB regular season. I calculated the CO2 emissions that result from travel between the cities that the Cubs visited in 2014 by accounting for inter-city distances and air travel emissions data. I measured the distance between MLB cities in Google Earth. I assigned each distance one of four designations using (Ross 2009) because CO2 emissions vary with the distance of the flight. Emissions figures were given in units of kilograms of CO2 per passenger per kilometer. This was problematic because the Cubs declined to say exactly who traveled with the team on road trips. But I assumed a full plane because of the weight of the team's equipment and because the number of passengers on an airplane has a minimal effect on overall fuel consumption (Ross 2009). The Chicago Cubs traveled on an Airbus A319 in 2014 (MetroAir 2014), which seats 124 passengers and reportedly burns 15% less fuel than jets of similar size (Airbus 2014). Due to this fuel-burn reduction, I reduced the emissions from (Ross 2009) by 15%. The equation used to calculate the amount CO2 emissions for a flight between cities is below.

$$124 * \text{Distance between airports} * \text{Emissions (for flight designation)} * 0.85$$

I entered the emissions data generated by the above equation into Table 1, which can be found in Appendix B. I had to use numbers to represent the cities or else the model would not work. I then used the formula below to look up the emissions associated with travel between two cities.

Look up function: $I26 = INDEX(\$C\$4{:}\$U\$22, G26 + 1, H26 + 1)$

Column G is the "From" column; column H is the "To" column. If G26=1 and H26= 5 then I26 contains the emissions value for travel from city 1 to city 5. I copied and pasted the formula from I26 through I76. I used the formula $G27 = H26$ so destinations only had to be entered into the "To" column[1].

To identify game-scheduling constraints and heuristics, including division specific constraints, I read the 2012 Basic Agreement and examined the schedules of 6 MLB teams, one from each division in each league (MLB and MLBPA 2012). I must note that each year Major League Baseball accepts competing scheduling proposals from outside groups. Therefore the only constraints that are consistent year to year are those outlined in (MLB and MLBPA 2012). All other constraints are formulated by the groups which bid to create the schedule. I attempted to calculate the company which has created the MLB schedule for the last 3 years, The Sports Scheduling Group. But the company was unresponsive.

I only programmed 4 constraints into Solver: 1) the variable cells must be greater than or equal to 0; 2) the variable cells must be less than or equal to 18; 3) the values of the variable cells must be integers; 4) H26 = 0 because it is the second round of the schedule and is traditionally played at home. These constraints ensure that Solver chooses numbers which correspond to values in Table 1. Because of Solver's limitations, I had to input my additional constraints as "penalties." I constrained my model not to allow the Cubs to play more than three consecutive series at home or on the road.

Home constraint: $K26 = IF(AND(H26 = H27, H27 = H28, H28 = H29), 10000000, 0)$

Away constraint: $L26 = IF(AND(H26 > 0, H27 > 0, H28 > 0, H29 > 0), 10000000, 0)$

I copied and pasted the formulas from K26 and L26 through K76 and L76, respectively. I also constrained my model to require that certain cities be visited a certain number of times.

Visitation constraint: $J26 = IF(E26 = D26, 0, 10000000)$

In column D are the numbers of time each city must be visited. In column E are the numbers of times each city is visited by the model. For example Chicago is represented by the "0" in the

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[1] Snapshots of my model with explaining the individual cell entries are available in the Appendix B.

model. Column E contains a COUNTIF function which counts how "0" are in the "To" column of the model. If this condition is not met $1*10^7$ is added to the target cell. I copied and pasted the formula from J26 through J44 because there are 19 visitation requirements that must be fulfilled. Stating the constraint in this way allowed me to add required visits to certain cities and remove required visits from others. In this way I was able to program my model to remove interleague play from the schedule.

Any penalties that the model incurs are added to the target cell. The resulting formula for the target cell is below.

$$I78 = SUM(I26{:}I76) + SUM(J26{:}J76) + SUM(K26{:}K76) + SUM(L26{:}L76)$$

This formula represents the total CO2 from travel plus the penalties. I included the penalties because Solver initially produced resulted which did not adhere to the constraints. It is also interesting to note that if the imposed penalty was too large, Solver would accept an arbitrary number of penalties rather than find a solution resulting in no penalties.

For my model, I chose not to change the city where the Cubs began the 2014 regular season. Because I could not obtain specific information from the Cubs I also assumed that the team flew on each trip except when traveling between Chicago and Milwaukee, which is less than 100 miles. I initially entered "0" for the emissions between Chicago and Milwaukee. But this led to Milwaukee being visited too many times and Chicago being visited too few. To correct the problem I entered "100" as the emissions between Chicago and Milwaukee.

Data analysis

To analyze the potential of my model for reducing CO2 emissions through different scheduling arrangements, I compared the CO2 emissions from the Cubs' official schedule to the emissions generated by the optimized schedule. I manipulated the constraints in the model to determine how the optimal solution was affected by the elimination of interleague play.

RESULTS

My model produced a schedule with the same opponents as the official schedule and reduced emission. When I removed interleague play from the schedule and added a visit to Miami, Washington DC, and Philadelphia, the best schedule produced by my model produces more emissions than the official schedule. The same schedule also includes consecutive visits to Philadelphia, which is not specified as a constraint in the model but nonetheless violates the schedule parameters. Figure 1 compares the CO2 emissions from each of the scheduling formats.

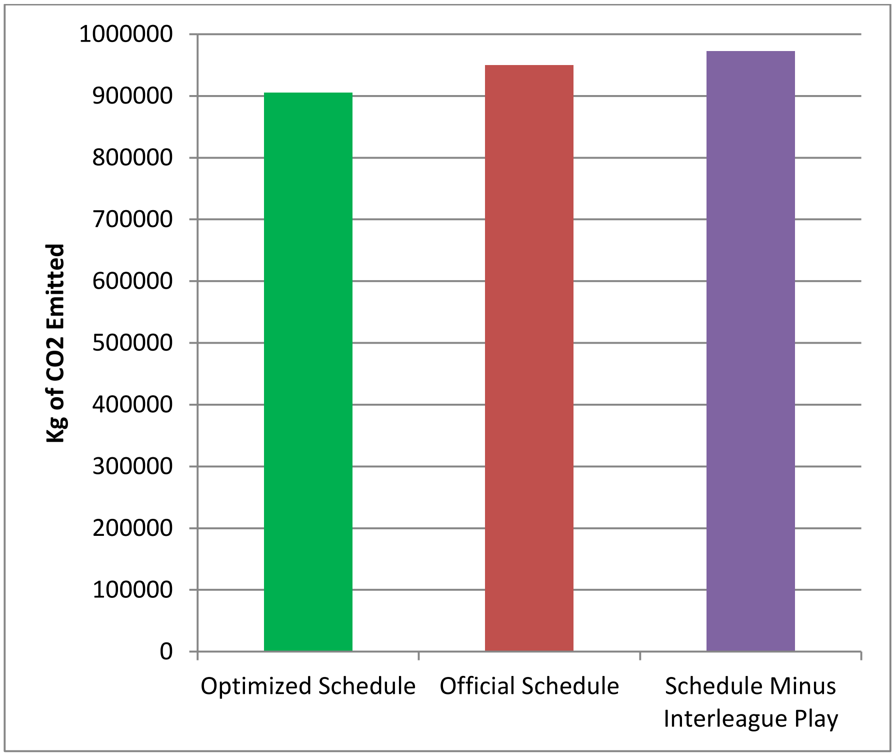

Figure 1. Figure 1 compares the emissions resulting from the schedules generated by my model to the official MLB schedule.

It shows that the optimized schedule produces 4.7% less CO2 than the official schedule. It also shows that the schedule without interleague play produces 2.3% more CO2 than the official schedule. More optimal schedules were created for both the format with and format without interleague when I removed the “Home Constraint,” the “Away Constraint,” and the constraint requiring that the second round be in Chicago. But these schedules comprised 26 consecutive rounds in Chicago and consecutive rounds in the same away city.

Tables 1-4 (see appendix A) show the Cubs’ official 2014 schedule, the CO2-optimized schedule for the Cubs with and without interleague play, and the unconstrained optimized schedule.

DISCUSSION

Improvements to travel logistics can help to reduce GHG emissions resulting from corporate air travel. In the case of MLB, the regular season schedule can be optimized to minimize CO2 emissions. As expected, my model produced a schedule that satisfied all of my expressed constraints and resulted in lower emissions than the actual MLB schedule. However, the optimized schedule contained elements that the Cubs might find undesirable. This fact could be problematic if I were creating an official schedule because the MLB Players' Association, which has representatives from each team and must approve the schedule (MLB and MLBPA 2012). Nonetheless, my model provides proof of concept that, at least in the case of the Cubs, changes to the way the MLB schedule is created can reduce CO2 emissions.

Comparison to other TSP-type models

The model on which I based mine is intended to answer a basic TSP problem where each destination must be visited once before returning to the origin. The TSP problem that my model must solve is much more complex. It requires multiple visits to each destination as well as the point of origin. The model is required to return to the origin (Chicago) at least every fourth round and it must depart from the origin at least every fourth round. Nemhauser and Trick (1998) built a TSP-type model that schedules teams for a double round-robin (each team in the league plays every other team twice). But in order to simply the process, they schedule only one round-robin and simply mirror the schedule in the second half. I could not use this methodology because certain destinations must be visited more than others. I instead added programming intended to ensure that all constraints are satisfied simultaneously.

Constrained scheduling

The highest reduction in CO2 emissions that I was able to achieve from my model while respecting real-world parameters was 4.7%. For comparison, Russel and Leung (1993) examined reducing travel to reduce cost and achieved a 5.6% reduction in miles traveled using a linear programming approach. An analysis of the Major League Soccer (MLS) schedule found a 25% reduction in miles traveled (Birge 2004). An optimized schedule for a German soccer league theoretically increased profits by 35% (Bartsch et. Al 2006). It is possible that MLS, which was founded in 1993 and is a relatively young organization, may not yet have exploited measures to reduce travel while MLB has, thereby increasing potential for gains from travel optimization. Russel and Leung (1993) examined the schedule of a league which had already taken measures to reduce travel to reduce cost, which may explain why the improvement they achieved is modest compared to that of Birge (2004). The German soccer league had created its schedule by hand prior to the work of Bartsch et. al and did not attempt to schedule marquee games on dates where profits could be maximized.

However the optimized schedule contains a few elements that Chicago might find undesirable. In the optimized schedule Chicago finished the season with two rounds on the road against San Diego and Los Angeles, respectively. Finishing the season against Western division teams is undesirable because teams prefer to play other teams from their own divisions at the end of the season with spots in the playoffs at stake. I tried to solve this issue by creating a constraint that imposed a penalty if Chicago were finishing the season on the road against a non-divisional opponent. But Solver ignored the constraint when I tried to implement it and accepted the penalty. I believe that I was asking Solver to satisfy too many constraints at this point. Additionally, two out three visits to Cincinnati are in the last third of the season. These series would ideally be spread evenly throughout the season to prevent injuries from affecting the outcome of the season series.

Interleague play

In the case of the Cubs, removing interleague play has the effect of increasing CO2 emissions. When I changed the parameters of my model to remove AL East opponents from the optimized result was 2.3% higher in terms of emissions than the official schedule. This result suggests that interleague play is beneficial to the environment because it reduces the distance the Cubs must travel to complete their schedule. However, the interleague opponents change each season with the NL central (the Cubs' division) playing either the AL East, AL Central, or AL West division. This fact means that the consequences, positive or negative, of interleague play change from season to season. I hypothesize that interleague play is most beneficial when the NL East plays the AL East, the NL Central plays the AL Central, and the NL West plays the AL West because this involves having teams from the same geographic region play each other rather than having a team from the East Coast travel to Seattle.

The schedule without interleague play also contained an element that would make it unacceptable as an official schedule. It contains two consecutive rounds in Cincinnati. While this did not violate any of my expressed constraints, it is unacceptable on a practical scheduling level. I attempted to solve this problem by creating a constraint that imposed a penalty on the target cell if a road city were visited for consecutive rounds. But when I applied this constraint, this led either to Solver ignoring it and accepting the penalty or to a solution with much higher emissions. Again, I believe that this is result of there being too many constraints for Solver to accommodate.

Unconstrained scheduling

An optimization with only the visitation constraint, which I shall call an unconstrained optimization, resulted in the highest reduction of emissions (29%). I expected Solver to generate a schedule with 26 consecutive rounds on the road, because the Cubs begin the season in Pittsburg, followed by 26 consecutive rounds at home. However, the resulting schedule involved to separate instances of 9 consecutive rounds in Chicago and 12 consecutive rounds on the road. This result could be explained by the limitations of my model, and those of the Evolutionary solving method, or by the geographically centric location of Chicago, which is in the center of the country.

Limitations and future improvements

My model is limited in that it can only create a schedule for one team. The most optimal schedule for the Cubs may not lead to the most optimal schedule for the entire league. One way to test the generalizability of my model would be to optimize a schedule for a team other than Chicago. To do this my CO2 emissions matrix would have to be expanded from 19x19, which only encompasses the Cubs’ 2014 opponents, to 30x30 which encompasses the entire league. One way to test the effectiveness of my model would be to create a schedule for the rest of the league using the expanded emissions matrix. I would begin by constraining the model to place teams at home in the required time slots to satisfy the Chicago’s schedule as in (Birge 2004). But this approach is not guaranteed to work because Solver has difficulties when too many constraints are involved.

My model, in its current state, is limited in that it does not clearly indicate whether or not interleague play is beneficial for the environment because it produces data for one team in one season. To better determine the effect of interleague play on CO2 emissions, one could use the

30x30 CO_2 emissions matrix to compare the effects of the Cubs playing the AL East, AL Central, and AL West. With the expanded matrix, one could also create schedules with and without interleague play for teams from the East Coast and West Coast, respectively. Comparing the emissions generated by these respective schedules would clarify the effect of interleague play on CO_2 emissions.

My model is also limited because of the computing power of Excel Solver and the nature of the Evolutionary Solving method. Frontline Systems, Inc., the creator of Excel Solver, says that it is important to understand what the method can and cannot do. “At best, the Evolutionary method…will be able to find a good solution to a reasonably well-scaled model…it cannot determine whether a given solution is optimal… It knows only that a new candidate solution is ‘better’ than other solutions found earlier.” To evaluate the solution arrived at by Excel Solver, one can run the program multiple times to see if a more optimal solutions is attained (Frontline Systems, Inc. 2015). More powerful software could be used to build a model and produce a schedule that the program knows to be optimal. Such software could also be used to possibly build a model that simultaneously schedules all 30 MLB teams. If such a model were built, I would advise the researchers to continue to solicit MLB for information relating to the scheduling preferences. Doing so is not strictly necessary, but gathering information regarding scheduling preferences is more likely to result in a schedule that would be acceptable to MLB.

My model could also be used to research other scheduling formats such as allowing four consecutive rounds at home as opposed to three. My model could also be used to research the effects of altering the structure of MLB. Baseball enthusiasts have proposed doing away with the two league structure and removing the divisions. Under the proposed structure, Chicago would not have to play its current divisional opponents 18 times throughout the season. Instead the Cubs would play all of its opponents an equal number of times. My model could provide insight into how this change in the structure of MLB would affect CO_2 emissions. A model similar to mine could indicate if there are improvements to be made in terms of emissions in other professional sports leagues.

Conclusion

MLB can take steps to improve its carbon footprint by configuring the schedule to reduce travel. And while my results do not indicate if optimizing the schedule of all of MLB would be beneficial, they do indicate further research into travel optimization for MLB is warranted. In the case of the Cubs 2014 schedule, emissions could be reduced by up to 29%, thought 5% is achievable without radically deviating from the scheduling status quo. This figure raises the questions of whether or not changing the order of the schedule is a worthwhile endeavor. Would a possible reduction in profit caused by an optimal schedule outweigh the reward of mitigating 45 metric tons of CO2 in the eyes of team owners?

Luckily, environmental concerns have become more and more prevalent in professional sports in recent years as organizations have realized the importance of a healthy environment to the success of their sports (Trendafilova et. al 2013). Since 2005 MLB has partnered with the Natural Resources Defense Council (NRDC) to promote sustainability throughout the league. And positive results can be seen. The Pittsburg Pirates organization currently diverts 65% of the waste from its ballpark out of the waste stream (Berry 2013). Six MLB stadiums currently employ some kind of solar power or heating (NRDC 2015) and others are LEED certified facilities. There are other steps MLB can take toward being more sustainable. MLB teams could sod their fields with low-water grass. Teams could promote food sustainability by having a monthly or bi-weekly game with locally-sourced concessions. A natural outcome of this increasing concern for the environment would be for professional sports leagues prioritize reducing travel.

ACKNOWLEDGEMENTS

Special thanks to Joe Kantenbacher, my de-facto mentor, without whom I would not have completed this project. Thanks to Professor Matthew Potts who helped to get my model off the ground. Thanks to Kurt and Tina for embracing my project and encouraging me to continue with it. Shout-out to the Super Modelers, the best ESPM 175 work-group.

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Appendix A: Schedule results

Table 1. Table 1 shows the optimal schedule generated by my model. The schedule produces 905603 kg of CO_2. The first round, which is always in Pittsburg, is not included in the table.

Round	Location	Round	Location	Round	Location
1.	Chicago	18.	Chicago	35.	Arizona
2.	Colorado	19.	Chicago	36.	Chicago
3.	Miami	20.	San Francisco	37.	NYM
4.	Pittsburg	21.	Philadelphia	38.	Chicago
5.	Chicago	22.	Chicago	39.	Chicago
6.	Chicago	23.	Milwaukee	40.	Chicago White Sox
7.	Toronto	24.	Chicago	41.	Milwaukee
8.	Chicago	25.	Chicago	42.	Chicago
9.	Chicago	26.	Chicago	43.	Chicago
10.	Boston	27.	Milwaukee	44.	Cincinnati
11.	St. Louis	28.	Chicago	45.	St. Louis
12.	Chicago	29.	Chicago	46.	Cincinnati
13.	Chicago	30.	St. Louis	47.	Chicago
14.	Chicago	31.	Cincinnati	48.	Chicago
15.	NYY	32.	Chicago	49.	Chicago
16.	Washington DC	33.	Chicago	50.	San Diego
17.	Pittsburg	34.	Atlanta	51.	Los Angeles

Table 2. Table 2 shows the optimal schedule generated by my model when interleague play is removed from the schedule. This schedule format produces 972608 kg of CO_2. The first round, which is always in Pittsburg, is not included in the table.

Round	Location	Round	Location	Round	Location
1.	Chicago	18.	Chicago	35.	Chicago
2.	Pittsburg	19.	Chicago	36.	Milwaukee
3.	Washington DC	20.	Chicago	37.	Chicago
4.	Pittsburg	21.	Miami	38.	Chicago
5.	Chicago	22.	Chicago	39.	St. Louis
6.	San Diego	23.	St. Louis	40.	Chicago
7.	Los Angeles	24.	Chicago	41.	Milwaukee
8.	Milwaukee	25.	Chicago	42.	Colorado
9.	Chicago	26.	Chicago	43.	Chicago
10.	Miami	27.	Philadelphia	44.	St. Louis
11.	Cincinnati	28.	Philadelphia	45.	Chicago
12.	San Francisco	29.	Chicago	46.	Chicago
13.	Chicago	30.	Chicago	47.	Chicago
14.	Chicago	31.	Cincinnati	48.	Cincinnati
15.	Chicago	32.	Chicago	49.	Chicago
16.	New York Mets	33.	Chicago	50.	Arizona
17.	Washington DC	34.	New York Mets	51.	Atlanta

Table 3. Table 3 shows the official 2014 MLB regular season schedule, which produces 950461 kg of CO2.

Round	Location	Round	Location	Round	Location
1.	Chicago	18.	Milwaukee	35.	Los Angeles
2.	Chicago	19.	Chicago	36.	Colorado
3.	St. Louis	20.	Chicago	37.	Chicago
4.	New York Yanks	21.	Pittsburg	38.	Chicago
5.	Chicago	22.	Philadelphia	39.	New York Mets
6.	Chicago	23.	Miami	40.	Chicago
7.	Milwaukee	24.	Chicago	41.	Chicago
8.	Cincinnati	25.	Chicago	42.	Cincinnati
9.	Chicago	26.	Chicago	43.	St. Louis
10.	Chicago	27.	Boston	44.	Chicago
11.	Chicago White Sox	28.	Washington DC	45.	Chicago
12.	Atlanta	29.	Cincinnati	46.	Toronto
13.	St. Louis	30.	Chicago	47.	Pittsburg
14.	Chicago	31.	Arizona	48.	Chicago
15.	Chicago	32.	Chicago	49.	Chicago
16.	San Diego	33.	Chicago	50.	Chicago
17.	San Francisco	34.	Chicago	51.	Milwaukee

Table 4. Table 4 shows the unconstrained schedule produced by my model. It produces 677075 kg of CO2. It does not contain 26 consecutive rounds in Chicago as I thought it would. This is likely due to the Chicago's geographically centric location.

Round	Location	Round	Location	Round	Location
1.	New York Yankees	18.	Chicago	35.	Chicago
2.	Pittsburg	19.	Cincinnati	36.	Chicago
3.	Washington DC	20.	Atlanta	37.	Chicago
4.	Milwaukee	21.	Colorado	38.	Chicago
5.	Chicago White Sox	22.	San Diego	39.	Chicago
6.	Boston	23.	Chicago	40.	Chicago
7.	Philadelphia	24.	Chicago	41.	Chicago
8.	Pittsburg	25.	Chicago	42.	St. Louis
9.	New York Mets	26.	Chicago	43.	Arizona
10.	Toronto	27.	Chicago	44.	Milwaukee
11.	Miami	28.	Chicago	45.	St. Louis
12.	Chicago	29.	Chicago	46.	Chicago
13.	Chicago	30.	Chicago	47.	Cincinnati
14.	Chicago	31.	Chicago	48.	Cincinnati
15.	Chicago	32.	Milwaukee	49.	St. Louis
16.	Chicago	33.	Chicago	50.	Los Angeles
17.	Chicago	34.	Chicago	51.	San Francisco

Appendix B: Excel formulas and screenshots of the model spreadsheet

City	Times Needed to Visit	Times Visited
Chicago	26	38
Pittsburgh	2	1
St. Louis	3	2
New York Yankees	0	0
Milwaukee	3	2
Cincinnati	3	2
Chicago White Sox	0	0
Atlanta	2	1
San Diego	1	1
San Francisco	1	1
Philadelphia	2	0
Miami	1	0
Boston	0	0
Washington DC	2	0
Arizona	1	0
Los Angeles Dodgers	1	1
Colorado	1	0
Toronto	0	0
New York Mets	2	2
Total	51	51

Table 5. I used Table 5 to ensure that my "Visitation Constraint" was satisfied. If the value under "Times Needed to Visit" equaled the value under "Times Visited" no penalty was imposed. If the values differed 1*107 was added to the target cell.

Table 6. Table 6 shows the emissions resulting from travel between the 19 cities that the Cubs visited during the 2014 MLB regular season.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	0	25014.96144	16035.51384	24148.8264	100	15415.12944	0	35992.54008	58808.7732	62992.31	22538.736	40462.2168	28819.9436	36284.32944	49305.2768	59173.8788	31184.698	26635.54968	24148.8264
1	25014.96144	0	34089.64848	19247.47344	27225.19944	15709.95432	25014.96144	31892.69088	82538.67676	88272.3946	15719.06088	34447.882	29437.33464	8374.93644	61981.7348	83276.36082	44751.1536	9898.05076	19247.47344
2	16035.51384	34089.64848	0	29612.3408	20022.28992	18809.59968	16035.51384	28570.69368	53022.7348	59143.5236	27448.0572	36089.3816	35178.7256	24070.8304	43130.734	53865.3024	26998.8424	22433.336	29612.3408
3	24148.8264	19247.47344	29612.3408	0	24862.3844	34689.92256	24148.8264	25330.9928	94823.55268	100209.6402	0	40261.3244	8397.9558	8987.1418	80904.28112	95517.35872	55271.76	20909.80008	0
4	100	27226.33776	20022.28992	24862.3844	0	19825.36056	100	22734.1476	58959.706	62434.9548	26293.2948	43158.5596	29049.7156	21537.6468	57104.21278	59142.048	30996.032	26297.46864	24862.3844
5	15415.12944	15709.95432	18809.59968	34689.92256	19825.36056	0	15415.12944	22619.17728	72991.4499	79622.849	30647.74824	32444.0172	25081.4056	24542.93808	53576.7172	73921.85786	37071.288	25161.04584	34689.92256
6	0	25014.96144	16035.51384	24148.8264	100	15415.12944	0	35992.54008	58808.7732	62992.31	22538.736	40462.2168	28819.9436	36284.32944	49305.2768	59173.8788	31184.698	26635.54968	24148.8264
7	35992.54008	31892.69088	28570.69368	25330.9928	22734.1476	22619.17728	35992.54008	0	73718.46748	83410.41908	22601.3436	37070.52912	31790.3264	33531.49224	53955.314	75485.22444	41096.3032	24970.7356	25330.9928
8	58808.7732	82538.67676	53022.7348	94823.55268	58959.706	72991.4499	58808.7732	73718.46748	0	28019.36736	92478.86644	95861.3527	100718.4798	88653.47884	18265.86216	4922.03244	28284.09	84532.82368	94823.55268
9	62992.31	88272.3946	59143.5236	100209.6402	62434.9548	79622.849	62992.31	83410.41908	28019.36736	0	98299.37064	106045.1745	105174.4018	95099.91148	22176.16	21239.154	32172.7176	88431.1797	100209.6402
10	22538.736	15719.06088	27448.0572	0	26293.2948	30647.74824	22538.736	22601.3436	92478.86644	98299.37064	0	38942.7704	16548.13728	5442.16036	81157.85244	93277.1555	53484.176	20505.31704	0
11	40462.2168	34447.882	36089.3816	40261.3244	43158.5596	32444.0172	40462.2168	37070.52912	95861.3527	106045.1745	38942.7704	0	46958.0188	35685.278	82137.22924	96070.56116	60702.3896	46228.8616	40261.3244
12	28819.9436	29437.33464	35178.7256	8397.9558	29049.7156	25081.4056	28819.9436	31790.3264	100718.4798	105174.4018	16548.13728	46958.0188	0	24070.91472	89643.52212	101192.8958	59961.2168	26273.94336	8397.9558
13	36284.32944	8374.93644	24070.8304	8987.1418	21537.6468	24542.93808	36284.32944	33152.05224	88653.47884	95099.91148	5442.16036	35685.278	24070.91472	0	77238.89072	89601.82588	50575.3468	21382.96176	8987.1418
14	49305.2768	61981.7348	43130.734	80904.28112	49655.8372	53576.7172	49305.2768	53955.314	18265.86216	22176.16	81157.85244	82137.22924	89643.52212	77238.89072	0	21814.38504	35796.3696	73693.74064	80904.28112
15	59173.8788	83276.36082	53865.3024	95517.35872	59142.048	73921.85786	59173.8788	75485.22444	4922.03244	21239.154	93277.1555	96070.56116	101192.8958	89601.82588	21814.38504	0	28183.96	84805.54618	95517.35872
16	31184.698	44751.1536	26998.8424	55271.76	30996.032	37071.288	31184.698	41096.3032	28284.09	32172.7176	53484.176	60702.3896	59961.2168	50575.3468	35796.3696	28183.96	0	45605.9476	55271.76
17	26635.54968	9898.05076	22433.336	20909.80008	26297.46864	25161.04584	26635.54968	24970.7356	84532.82368	88431.1797	20505.31704	46228.8616	26273.94336	21382.96176	73693.74064	84805.54618	45605.9476	0	20909.80008
18	24148.8264	19247.47344	29612.3408	0	24862.3844	34689.92256	24148.8264	25330.9928	94823.55268	100209.6402	0	40261.3244	8397.9558	8987.1418	80904.28112	95517.35872	55271.76	20909.80008	0