Game Schedule for U.S. National Football League

After graduating from the GWU's Master of Science in Business Analytics program, Liang Johnson was hired by a major consulting firm located at the Washington D.C. With excitement, he started his first assignment that dealt with analyzing and developing a schedule for the National Football League (NFL).

NFL is the professional American football league consisting of 32 teams, divided equally between the National Football Conference (NFC) and the American Football Conference (AFC). Each conference is further divided into four division of four clubs and every NFL team is based in the contiguous United States. Since the analysis including all the teams right-away was estimated to be computationally intensive, Liang was asked to develop a preliminary analysis for a subset of teams, namely for teams in the East, North, and South divisions. This setup was agreed by the NFL schedulers to approximate the overall problem sufficiently well to come up with recommendations. Figure 1 shows all the 24 teams that are included in the analysis.

The scheduling of games for the selected subset of teams is constrained by the following four main rules:

1. The season was limited to 12 weeks.
2. Each team would play once per week.
3. All 12 games that a team played would need to be against a different opponent.
4. Each team would play at most six home games (i.e., on their home stadium).

Whereas the overall goal was to reduce the total distance that the teams travelled, there were also other considerations, such as the fairness of the game schedule for all teams and the fairness of the game schedule for broadcasting companies. With these thoughts in mind, Liang embarked on the analysis of the NFL game scheduling.

Division	Club	City	Stadium	Capacity
American Football Conference				
East	Buffalo Bills	Orchard Park, New York	Bills Stadium	71,608
	Miami Dolphins	Miami Gardens, Florida	Hard Rock Stadium	64,767
	New England Patriots	Foxborough, Massachusetts	Gillette Stadium	65,878
	New York Jets	East Rutherford, New Jersey	MetLife Stadium[C]	82,500
North	Baltimore Ravens	Baltimore, Maryland	M&T Bank Stadium	71,008
	Cincinnati Bengals	Cincinnati, Ohio	Paul Brown Stadium	65,515
	Cleveland Browns	Cleveland, Ohio	FirstEnergy Stadium	67,895
	Pittsburgh Steelers	Pittsburgh, Pennsylvania	Heinz Field	68,400
South	Houston Texans	Houston, Texas	NRG Stadium	71,995
	Indianapolis Colts*	Indianapolis, Indiana	Lucas Oil Stadium	67,000
	Jacksonville Jaguars	Jacksonville, Florida	TIAA Bank Field[E]	67,814
	Tennessee Titans*	Nashville, Tennessee	Nissan Stadium	69,143
National Football Conference				
East	Dallas Cowboys	Arlington, Texas	AT&T Stadium	80,000
	New York Giants	East Rutherford, New Jersey	MetLife Stadium[C]	82,500
	Philadelphia Eagles	Philadelphia, Pennsylvania	Lincoln Financial Field	69,176
	Washington Football Team*[G]	Landover, Maryland	FedExField	82,000
North	Chicago Bears*†	Chicago, Illinois	Soldier Field	61,500
	Detroit Lions*	Detroit, Michigan	Ford Field	65,000
	Green Bay Packers	Green Bay, Wisconsin	Lambeau Field	81,441
	Minnesota Vikings	Minneapolis, Minnesota	U.S. Bank Stadium	66,860
South	Atlanta Falcons	Atlanta, Georgia	Mercedes-Benz Stadium	71,000
	Carolina Panthers	Charlotte, North Carolina	Bank of America Stadium	75,523
	New Orleans Saints	New Orleans, Louisiana	Mercedes-Benz Superdome	73,208
	Tampa Bay Buccaneers	Tampa, Florida	Raymond James Stadium	65,618

Figure 1: Teams in AFC and NFC that are included in the analysis

Assignment

In this workshop, you will build an integer programming model and use the results of the optimization to support your recommendations. Make a report of about 3 pages (excluding figures, graphs and appendices) summarizing your results, your interpretation of the results and your conclusions and recommendations. You can include graphs and outputs in an appendix, but make sure to summarize and interpret the results in your report as well.

1. The plain vanilla schedule

To start, develop a schedule that minimizes the total travel distance of all teams. The distances between the home stadiums of each team are shown in miles in the file "distance.cvs". When calculating the distances that teams travel, you can assume that after each game the team that played away will travel back to their home stadium before the next game. Include in your model the four main rules.

Hint: You can specify your decision variable as follows: x_{ijk}= 1 if a team *i* plays a game **at home** against team *j* during week *k* and x_{ijk}= 0 otherwise. Remember that $x_{12k} = 0\ \forall k$ does not exclude that a team 1 plays a game away against team 2, as this is captured by decision variable x_{21k}.

- What is the objective function? What are the constraints?
- Write down the mathematical formulation of the problem.
- Copy the file "nfl.py" that can be found on blackboard. This python file contains a template for the model. Develop your optimization model and **save it as "nfl 1.py"**. Solve (i) the minimum total distance travelled by all teams and (ii) illustrate the optimal schedule for Cleveland Browns. How does the home and away game pattern look like for the Cleveland Browns?

2. Game pattern and bye week constraints

The NFL schedulers asked whether it would be possible to adjust the plain vanilla schedule (which followed the four main rules) to obtain a schedule in which no team would play more than (i) two

consecutive games at home and (ii) two consecutive games away. The logic behind these game pattern constraints was to provide a fairer schedule for the teams in terms of them having similar home/away game patterns.

- What is the mathematical formulation for the game pattern constraints?
- Adjust the model developed in part 1. by incorporating the game pattern constraints and **save the model as "nfl 2a.py"**. What are the implications of the game pattern constraints? What happened to the minimum total distance travelled by all teams and the optimal schedule for Cleveland Browns?

To further reduce the fatigue caused by the competition and travelling, the NFL schedulers asked to incorporate in the schedule a week when there are no games. This one-week long break is also referred as the *bye week*. Suppose that the schedulers requested the bye week to be assigned on week 9, which means that there are no games at week 9, and that the whole season is extended by a week up to 13 weeks.

- What are the required changes for the mathematical formulation to incorporate also the bye week constraint?
- Adjust the model "nfl 2a.py" by incorporating the bye week constraint and **save the model as "nfl 2b.py"**. What are the consequences for the minimum total distance travelled by all teams and the optimal schedule for Cleveland Browns?
- Would you recommend adding the game pattern and bye week constraints?

3. Fairness constraints

To judge the fairness of the schedule, in terms of travelled distance, the NFL schedulers suggested to assess the total distances that each team travel during the season.

- Use the model "nfl 2b.py", to evaluate the total distances that each team travels. Which team travels the most and which team travels the least? What is the difference in the distances of the teams that travel the most and the least?
- To set a maximum cap on the travelling amounts and reduce the overall deviation in the amounts that teams travel, the NFL schedulers asked to set a constraint on the total distance that any team needs to travel. What is the mathematical formulation for this constraint?

- Develop a python model to include constraints on the maximum allowed travelling distance that any team travels and **save the model as "nfl 3.py".** If the maximum allowed travelling distance is set for 11,000 miles and 10,990 miles, which teams would then travel the most and the least? How would the difference between the distances of these most travelling and least travelling teams change?
- What is the minimum of the maximum allowed travelling distance, that any team needs to travel, such that a feasible solution is obtained? Provide the answer in the accuracy of 1,000 miles. Hint: Set the constraint for the maximum allowed travelling distance tighter in intervals of 500 miles until no feasible solution is obtained.
- Plot a graph where you have on the y-axis the total amount travelled by all teams and on the x-axis the distance travelled by the team which travels the most. Interpret the graph and the scheduling logic behind the reduction in the distance travelled by the team which travels the most.

4. Scheduling to please broadcasting companies

Due to the broadcasting companies request, the NFL schedulers consider to set a constraint that each team plays equal number of games against teams at their own conference and the other conference. When adding these constraints, you can ignore the constraints on the maximum allowed travelling distance introduced in part 3 and append the constraints on the model "**nfl 2b.py"**.

- What is the mathematical formulation for these broadcasting constraints? Develop the model to include the broadcasting constraints and **save the model as "nfl 4.py"**.
- What is the optimal total travelling distance for all teams? How do the travelling distances and schedules change for Chicago Bears and Jacksonville Jaguars? Interpret the results and compare them with those obtained in part 3.