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DETERMINING AN OPTIMAL MATCH DAY DISTRIBUTION FOR THE TURKISH SUPER LEAGUE USING NON-LINEAR BINARY INTEGER PROGRAMMING

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by

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ABSTRACT

DETERMINING AN OPTIMAL MATCH DAY DISTRIBUTION FOR THE TURKISH SUPER LEAGUE USING NON-LINEAR BINARY INTEGER PROGRAMMING

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Sports scheduling has become an important topic of research in recent years. The decision to assign which teams to play in which venue and at which time is fundamental to the general welfare of everyone involved. This calls for fairness during scheduling of games while considering factors that influence those schedules. This thesis determines an optimal schedule that yields a fair distribution of games among teams over the course of a season. The goal is to ensure that the distributions track as close as possible to the ideal match day distribution for participating teams. Deviations for weekly fixtures are calculated and compared to the schedules by the Turkish Football Federation. The problem is formulated as a non-linear binary integer programming and solved with AMPL. Results demonstrate that the TFF schedules can be significantly improved by implementing the model.

Keywords: Sports Scheduling, Mathematical Model Application, Integer Programming, Advanced Concepts in Just-in-Time

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1. INTRODUCTION

In today's world, several entities contribute to the overall development of the sport and all these entities are mostly interdependent. Such stakeholders as teams, TV broadcasters, fans and even security agencies have a say on the scheduling of matches with each stakeholder in pursuit of a certain objective. For this reason, scheduling of sport has attained great importance. The demands placed by each stakeholder needs to be achieved through providing a balanced or optimal schedule.

In football, factors like the carry-over effect, breaks, rest duration, TV broadcasting revenue, club's revenue, fans' satisfaction etc. are aimed either to be minimized or maximized depending on the factor targeted. With football being one of the most popular sports, huge losses can be incurred by a team when these aforementioned factors are poorly optimized. Thus, scheduling becomes very important and has been a subject of research in the previous years. However, since the problem is priority based, generating a feasible schedule that satisfies all factors is difficult especially due to the respective constraints arising from stakeholders. Seasonal schedule directly or indirectly influences the results of the games and also the revenue for the clubs. A typical example is that of the carry over effect whereby a weak team plays consecutive matches against tougher sides and is likely to perform poorly on the latter match which will negatively impact the team's standing and financial return.

This thesis addresses the sports scheduling problems in the Turkish Super League (TSL) and provides alternative schedules to those outlined by the Turkish Football Federation (TFF). The Turkish Football Federation is the highest governing body that deals with, control, and organize all football related activities and policies in Turkey. They determine the teams to play, what time to schedule the match, which venue hosts the game, what rules to be applied and how those rules should be applied. With the FIFA and UEFA matches also put into consideration, the Turkish Football Federation schedules matches throughout the season with the objective of having fairly distributed game days for each team and matches are scheduled from Friday through Monday. Complications about the schedule arise due to some constraints like the minimum rest days and other matches played in weekdays. For instance, as a general requirement, each team must have a minimum of two-day rest between matches and UEFA games are scheduled during the weekdays. As in the case of the Turkish league, the Turkish Cup also needs to be considered. Typically, Champions League games are played on Tuesdays and Wednesdays while Europa League games are played on Thursdays. Therefore, constructing a schedule for the league games from Friday to Monday while ensuring the feasibility of achieving the minimum rest constraint is difficult and needs adequate planning.

This thesis aims to solve this scheduling problem by formulating a non-linear binary programming problem to solve for each round of the season. Each round will be solved separately taking into account the constraints related to that round. We will then compare the results from our model with the weekly schedules of the TFF to examine the deviations from both results. We will record improvements over the TFF schedule and present them at the end of the analysis. In order to illustrate the utility of our model, we will perform the numerical analysis based on the data from 2018-2019 season obtained from the official Turkish Football Federation website. We will first examine the schedules done by the TFF, then carry out optimization before presenting alternative results. The program we will use to solve the model is AMPL (A Mathematical Programming Language) and results obtained from the program will be compared to the real fixtures and deviations. The breakdown of the work done is as follows; a brief history of the Turkish Football Federation and their duties is outlined. Next, we discuss terminologies in sports scheduling. We shall study the literature review of previous works on this subject in the following section. The next sections will have the data analysis, methodology used in this thesis and the formulation of the problem at hand in that order. We then interpret the results of this work in the next section and afterwards discuss possible improvements in future.

1.1 TURKISH FOOTBALL FEDERATION AND ITS DUTIES

The Turkish Football Federation is the highest governing body in Turkey with headquarters in Ankara. It was formed on April 23 1923, joined FIFA the same year, and the UEFA in 1962. It is responsible for organizing the Turkish national teams, Turkish Football league, and the Turkish Cup competitions. It is responsible for all football related activities and policies in Turkey. Among the duties of the TFF are;

1. Organizing, regulating and monitoring of all football related activities in Turkey.
2. Overseeing the promotion, development, and football within Turkey.

3. Ensuring proper implementation of rules and regulations set by FIFA and UEFA while representing Turkey at the international level.
4. Ensuring the proper compliance to rules and regulations by clubs, players, technical staffs etc.
5. Fighting against improper conducts, violence, match fixing activities, discriminations and every other forms of misconducts.
6. Protecting the interest of all parties involved in the Turkish football community.

This governing body has the power to enact and implement necessary policies in accordance with the football regulations. Looking at the popularity of the game of football in Turkey, this organization has done a tremendous job and made several partnerships with leading companies. The revenue from this tournament is shared among the teams with major broadcasting corporations playing a big role in the revenue generation. From sponsorships provided by Turkcell, naming rights given to Spor Toto, to broadcasting rights awarded to Bein Sports, TFF has helped in the gradual rise and development of the Turkish League.

1.2 SCHEDULING IN FOOTBALL & TERMINOLOGIES

By definition, scheduling is the process of planning, arranging, or allocating certain tasks to certain machines at particular times. Likewise, scheduling in football is the arrangement of games to some time slots on particular days of the week at a designated venue. In particular, it is deciding which teams play, at what period of the day, on which day of the week, and at what time of the day. Sports are mostly in the form of a round robin format which is a format in which teams play one another in turns. A single round robin schedule (1RR) is when each team plays each other only once while in double round robin schedule (2RR), each team plays an opponent exactly twice. A triple round robin schedule (3RR) occurs when teams play one another three times in the course of a season whereas a quadruple round robin schedule (4RR) happens in the event that teams play each other four times. Football leagues, are mostly in the form of a double round robin schedule even though there are countries that have other formats. Table 1 below shows the types of schedules in some of the popular football leagues in Europe.

Country	Schedule Format	No. Of Teams
England	2RR	20
Spain	2RR	20
Italy	2RR	20
Germany	2RR	18
France	2RR	20
Portugal	2RR	16
Turkey*	2RR*	18*
Netherlands	2RR	18
Russia	2RR	16
Ireland	3RR	12
Scotland	3RR	12
Slovakia	3RR	12
Austria	4RR	10
Switzerland	4RR	10

Table 1: Scheduling Format of European Leagues.

*2020/2021 season had 21 teams participating in the Turkish Super League due to the effect of the covid pandemic. Bottom teams were not relegated meanwhile successful teams from the second tier were promoted to make up the 21 teams.

In a double round robin (2RR) format, "n" teams play each other twice, one in the venue of the hosting team known as "home team" and another at the opponent's team known as "away team". Where n is an even number, the total rounds "r" to be played is (n-1) *2 and the total games to be played throughout the season is $\frac{n}{2}$ * (n-1) *2.

Ex. For the Turkish Super League:

n = 18

r = (18-1) *2 = 34   Total games = 18/2 * (18-1) *2 = 306.

In practice, the number of home and away games played by each team should be balanced and the number of consecutive home games or consecutive away games should be as minimal as possible. A consecutive home or away game occurrence is termed as break. A team should ideally not have more than one break meaning not more than 2 consecutive home or away games and the total number of breaks for all teams should ideally be same [1] [2]. Most leagues prefer to have a mirrored double round robin schedule". That means games played in the second half of the season is identical to that of the first half albeit with the home and away venues changed. A schedule is said to be “compact” or “relaxed” respectively when each team plays exactly one game in a given round or when any team plays more than one game in any given round [1].

In addition to breaks, carry-over effect is one of the main effects to be minimized while scheduling of sports. When team “A” plays a difficult opponent team “B” in a challenging game and then has to face team “C” in the next match. Team “A” is likely to have some physical or psychological problems due to fatigue, injuries, or confidence loss as a result of playing team “B” in the previous round which might influence the outcome of the game. This situation is termed as carry-over effect.

2. LITERATURE REVIEW

Scheduling of sports has gained importance past few decades and many academicians have tried to come up with different valuable insights to the scheduling problems [4] [3]. Millions of fans all over the world frequently engage with sports, clubs make investments in players which affects the global economy, TV channels fight for broadcasting rights and several countries aspire to attain the right to organize and host important tournaments [3] [4] [5]. In this work, the focus will be on the round robin scheduling problems and a detailed look at [2] will be of help to interested readers. As already illustrated in Table 1, most European teams prefer the use of a double round robin schedule since it facilitates the convenient implementation of home and away patterns. Integer programming has been widely used for round robin schedules and where complications arise, other methods are tried. Due to constraints arising in the case of balancedness, several studies have been conducted to solve the problem. Taking constraints like fairness for breaks and carry-over effects, [6] proposed a formulation integrating integer programming to solve for this. These sort of constraints and objectives to be realized have been discussed in detail by [5]. According to [5], approaches like constraint programming, integer programming, metaheuristics, and hybrid methods have been used to solve problems related to the topic. While [7] combined integer programming and constraint programming to minimize the number of breaks for all teams in a double round robin competition, [8] used integer programming to obtain generic schedules for sport teams. Some studies aimed at achieving a number of the objectives in sport areas are [7] the minimization of breaks, minimization of carry-over effect by [9] [10], rest mismatch minimization [11], and minimization of travelled distance [12] [13] [14]. Sport scheduling mainly occurs by either of the two; a method "first schedule-then break" or "first break-then schedule".

	Round 1	**Round 2**	**Round 3**	**Round 4**
Team A	Home	Away	Home	Away
Team B	Away	Away	Home	Away
Team C	Home	Away	Home	Home

Table 2: Home and Away games pattern showing breaks.

Table 2 shows how patterns of home and away games are scheduled. The first row illustrating the games for team A has no breaks since no consecutive home or away games are seen but that cannot be said of second and third row for team B and team C respectively.

While attention was drawn to studies related to break minimization in the previous work, [15] utilized integer programming to bring an increase in income generated from ticket sales in Honduras league competition. The work by [16] also looked into similar case of attendance demand and fixture congestions in the English football league. They discussed and found issues related to the imbalance of revenue generation among top tier and lower tier clubs concluding that reorganization of the schedules would help solve and reduce the effects of such imbalance. Some researchers followed the “graph theory” for scheduling problems. A major method used by these researchers is the “circle method” whereby every team has a game in every round of the tournament and there should be no unassigned game at the end [3]. [17] made a case by transforming the sports scheduling problems into a maximum cut problem and argued that their method performs better that those of integer programming and constraint programming. While [18] developed a home-away schedule algorithm for a given round of a tournament, [19] ensured minimum breaks are achieved by providing theoretical results for the case of when the number of teams in a round robin schedules is even.

Another important factor that influences the outcome of matches is the distance traveled. To this end, a look at the work of [20] was necessary. The author considered factors like fairness of schedules and total distance traveled by each team in the Korea baseball league. The author generated an algorithm to tackle huge data problems and suggested integer programming to solve the problem. The results from the author’s analysis portrayed that a substantial improvement will be achieved through the implementation of the proposed solution model. The next work analyzed was that of [21] in which the Argentina professional basketball league was studied. The scheduling problems were studied by considering the total distance to be traveled by all teams and a variation of Traveling Tournament Problem was used for the formulation.

With rest mismatches a deciding factor in sports scheduling, [22] proposed an algorithm to obtain a zero-mismatch schedule under certain circumstances. The zero mismatch schedule provides equal amount of rest duration among teams. It is quite difficult to achieve that for the whole season which was why the authors presented their solution for certain weeks. This came as a result of their work on rest mismatch problem with an objective of minimizing the rest mismatches among teams using a combination of integer programming and constraint programming methods. They followed that work with a similar one albeit the objective is to minimize the total rest difference among teams [23]. They demonstrated that individual treatment of the rounds will yield a fair solution.

In terms of the match day distribution, top teams prefer playing on certain days and at certain times of the day. [24] provides some insight on this subject. The authors analyzed data from top European leagues and the results of this analysis shows that games played on non-frequent days have less attendance compared to those played on frequent days. To achieve fairness, there should be a balance between schedules on frequent and non-frequent days.

To make a ground for this thesis, in addition to the sport scheduling papers and works, timetabling papers were also studied since allocation of teams to time slots will be carried out. For this, we start with [25] in which the authors outline problems related to timetabling in Italian universities and describe how formulation should be done. [26] presented a more comprehensive approach using integer programming to minimize cost function. The authors provide constraints related to timetabling and satisfaction factor to course time scheduling.

All related literature paved way to a comprehensive formulation of the problem in question. The problem of this thesis will be defined in next section followed by its formulation.

3. PROBLEM DEFINITION

The Turkish Super League which is the top professional league in Turkey consists of 18 teams. The tournament is in the form of a double round robin meaning these teams play each other twice throughout the league with games played at home and away venue spaced to halves of the season. Winning a game earns a team three points, drawing a game earns one point, and losing a game brings no point. The team with highest points wins the competition while the bottom three teams get relegated to the second professional league. The top two teams qualify for the UEFA Champions League with the first team qualifying directly while the second team qualifies through play-offs. Teams ranked third and fourth qualify for the UEFA Europa League. Similarly, the third team goes to Europa League directly and the fourth team via play-offs. The winner of the Turkish Cup also joins these two teams to play in the Europa League.

With these international competitions and also national games taking place amid the league season, achieving a fair and balanced schedule for all teams proves to be difficult. The organizers of this tournament make a seasonal schedule taking into account several of the aforementioned factors. However, the most frequently complaints on these schedules are as follows:

1. Providing a fair amount of rest duration or simply providing equal rest time to all participating teams. The minimum days between matches is three days considering the international tournaments. The fact that not all the teams play in the UEFA Champions League or Europa League obviously means the rest time for all teams cannot be the same. Nonetheless, that should not be an excuse to have an ill-balanced schedule.
2. Since broadcasting bodies rely on top matches to bring in high revenue, matches for the top teams need to be played on days when the majority of spectators would come in numbers. As such, matches that carry high importance like the derbies and matches between top teams need to be played on the weekend and at a time of the weekend with the highest attendance.
3. Due to the fact that the ratings of games played on weekdays is low compared to those on the weekends, the distribution of matches need to be more for the weekend. However, scheduling one team’s games more on a particular day will cause controversies and complaints. As such the balance distribution of games for all teams is indeed a very important criterion.

4. Security is an essential part of this game that is why the need to employ security agents to cities and stadiums is important although some cities might have more than one team. This obligates the organizers to schedule matches in the safest possible way.

In view of the stated constraints, this study aims to find an optimal schedule for TSL such that a fair schedule is achieved without violating any or some of the constraints stated. Next section provides an overview of the data used.

3.1 DATA ANALYSIS

All data used in this thesis are obtained from the official TFF website. We examined data for 5 seasons starting from 2014-2015 to 2018-2019 and used those from 2018-2019 for analysis. Among these teams, five are considered the strongest and most popular teams. They are;

1. Galatasaray (GS)
2. Basaksehir (BSK)
3. Besiktas (BJK)
4. Trabzonspor (TS)
5. Fenerbahce (FB)

Team Index	Team
1	Galatasaray
2	Basaksehir
3	Besiktas
4	Trabzonspor
5	Malatyaspor
6	Fenerbahce
7	Antalyaspor
8	Konyaspor
9	Alanyaspor
10	Kayserispor
11	Rizespor
12	Sivasspor
13	Ankaragucu
14	Kasimpasa
15	Goztepe
16	Bursaspor
17	Erzurumspor
18	Akhisarspor

Table 3: 2018/2019 Season Participating Teams

League Standings 2014-2019					
Seasons	Galatasaray	Basaksehir	Besiktas	Trabzonspor	Fenerbahce
2014-2015	1	4	3	6	2
2015-2016	6	4	1	12	2
2016-2017	4	2	1	6	3
2017-2018	1	3	4	5	2
2018-2019	1	2	3	4	6

Table 4: League Standings for top teams from 2014 to 2019

Days Distributions 2014-2019				
	Friday	Saturday	Sunday	Monday
Galatasaray	20	72	55	19
Basaksehir	17	60	68	22
Besiktas	18	48	67	33
Trabzonspor	16	61	61	28
Fenerbahce	13	49	76	29

Table 5: Total day distribution for top teams from 2014-2019

Table 4 and Table 5 above display, respectively, the league standings of the aforementioned top five teams in Turkey from 2014 season to 2019 season and the total days distributions for these teams during the same period. TFF prefers to schedule matches in the format of 1-3-4-1 in order to boost the financial turnover as fans and pundits alike prefer that schedule, meaning one game to be scheduled on Friday, three games on Saturday, four games on Sunday, and one game on Monday. However, for one reason or another, this format of schedule is not quite maintained throughout the season as we shall see in the later sections. One of the reasons for that occurrence is because the administrators have a manual schedule for the rounds. This forces some teams to play more or less than their counterparts on particular days during the season. For that reason, the need to balance out such schedules while preserving the eligibility of the constraints arises.

To proceed onto the scheduling phase, the distribution for Saturdays and Sundays has to be decided since we know that Friday and Monday both should have one game each in every round. There are a total of seven slots to play in the weekends to be distributed in three playing periods of the day. As for Saturday, ideally a game in the noon, another in the afternoon, and finally one in the evening slot should be scheduled whereas for Sunday, due to the fact that there are four games to be played, another game has to be scheduled in addition to those games prescribed for noon, afternoon, and evening slots. To understand this situation clearly and come up with an assumption as to what the ideal distribution should be, we examined the playing times for five seasons and recorded the most frequent occurrences. We also analyzed and noted the percentage of games for each period so as to conform to the normal dispersion of games with respect to the months they are played in. We noticed that games in the early season months are seldomly fixed in the noon and afternoon times but they are fixed mostly in the evening. To support this claim, we made a comparison of the percentages of evening games in the months of August, September, October, and November. Figure 1 through Figure 5 below display the charts for each season from 2014 to 2019 for those months. We see that games in the month of August are played in the evenings in totality for all the five seasons. This can be interpreted as the result of the summer weather which is hot and thus is not suitable for games to be played in the noon or afternoon time. It can also be as a result of that month being mostly a vacation period and this could affect attendance thus the need to schedule all matches at night. Similar case can be said for September albeit with a few games played in the afternoon or noon. The scheduling of games in the noon and afternoon becomes normal as the season progresses towards October and November.

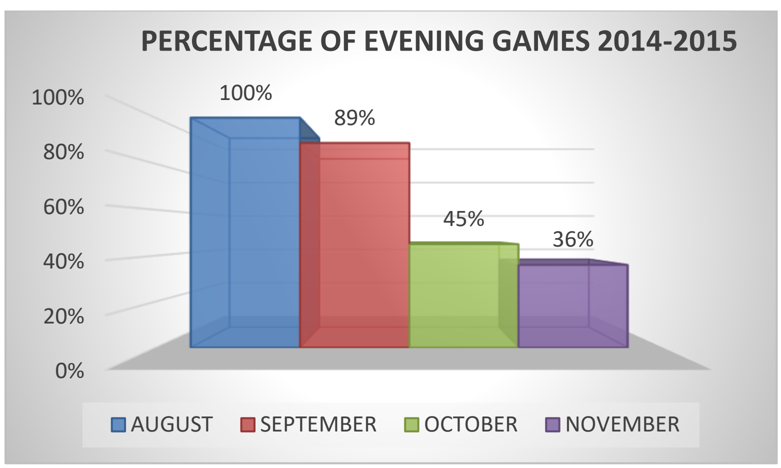

Figure 1: Percentage of games scheduled in the evening in early months of 2014-2015

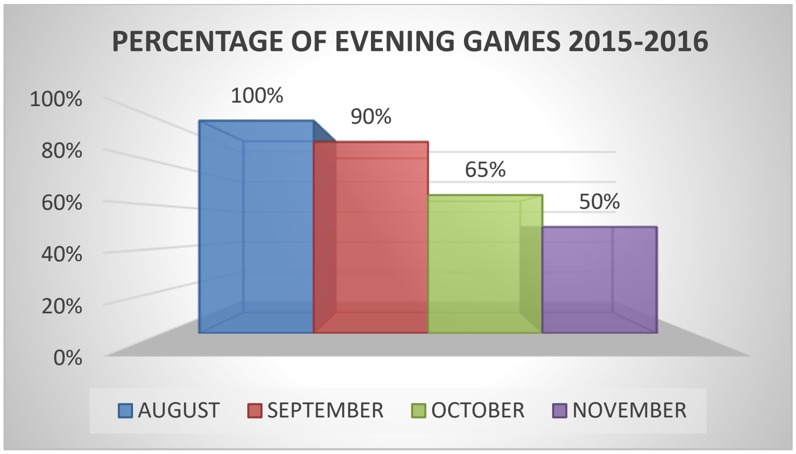

Figure 2: Percentage of games scheduled in the evening in early months of 2015-2016

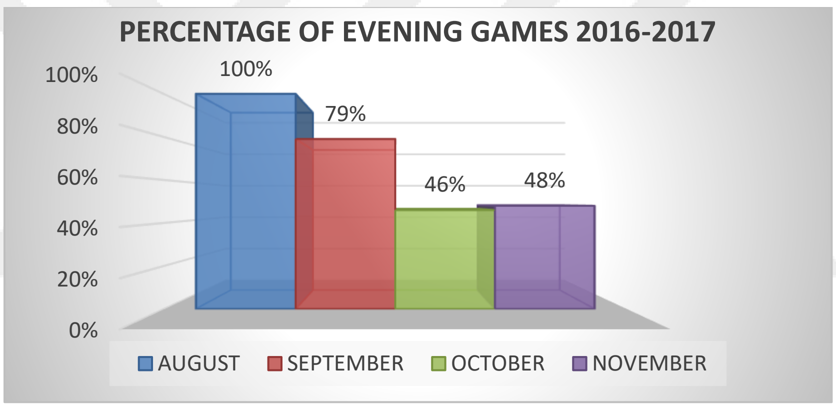

Figure 3: Percentage of games scheduled in the evening in early months of 2016-2017

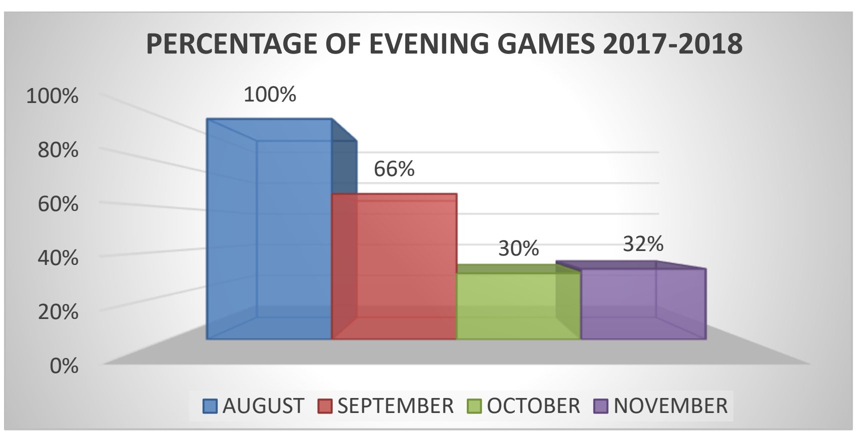

Figure 4: Percentage of games scheduled in the evening in early months of 2017-2018

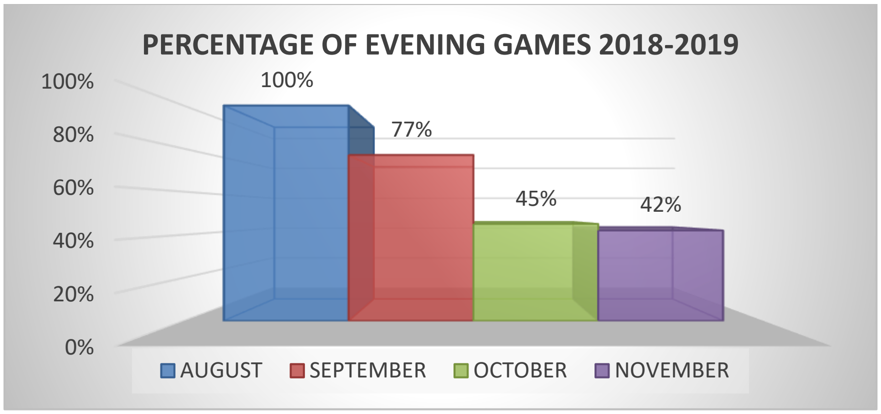

Figure 5: Percentage of games scheduled in the evening in early months of 2018-2019

We studied the data from 2018-2019 season in order to have a clearer picture of these schedules. Since Friday and Monday games are both scheduled in the evening, we analyzed Saturday and Sunday schedules. The blue, orange, and green segments in Figure 6 until Figure 13 represent evening, afternoon and noon games respectively. Figures 6-9 represent those periods games distribution on Saturdays in the early months of the season while Figures 10-13 show the same for Sundays.

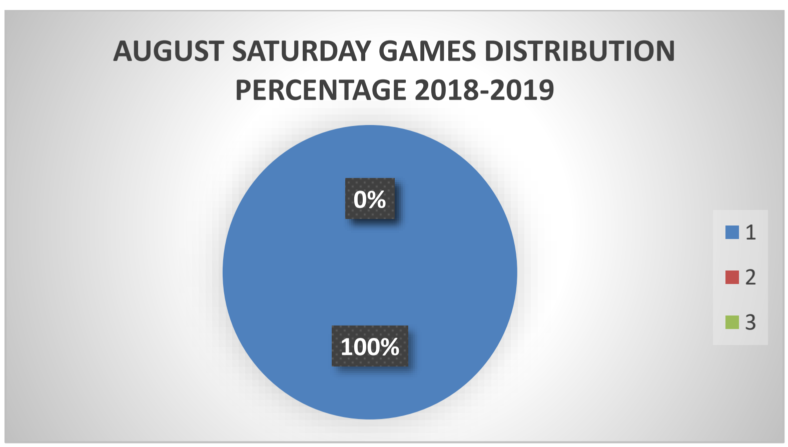

Figure 6: Distribution of Saturday games in August for 2018/2019

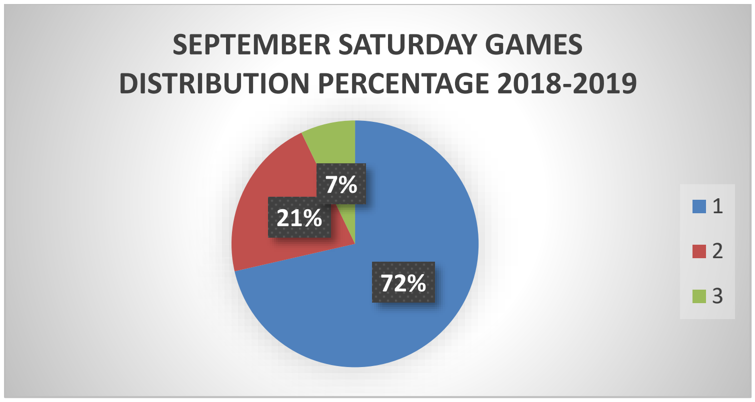

Figure 7: Distribution of Saturday games in September for 2018/2019

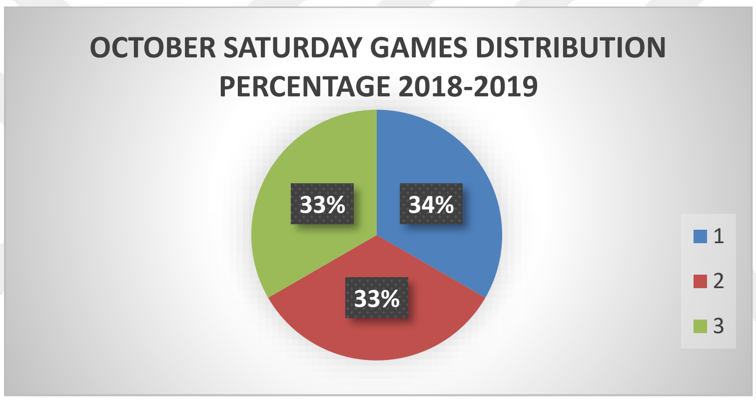

Figure 8: Distribution of Saturday games in October for 2018/2019

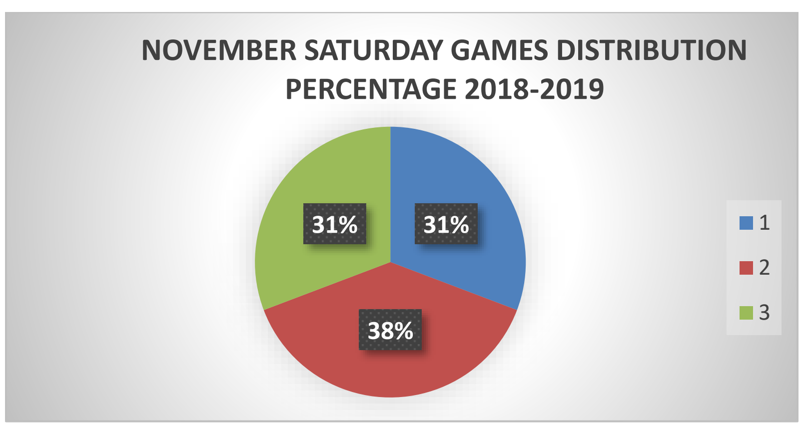

Figure 9: Distribution of Saturday games in November for 2018/2019

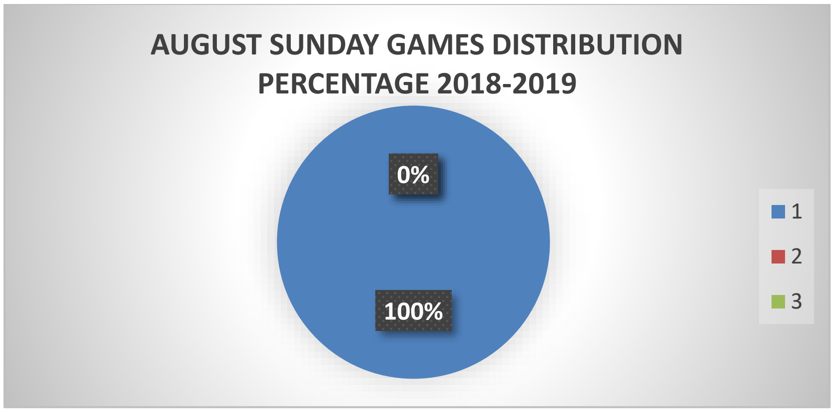

Figure 10: Distribution of Sunday games in August for 2018/2019

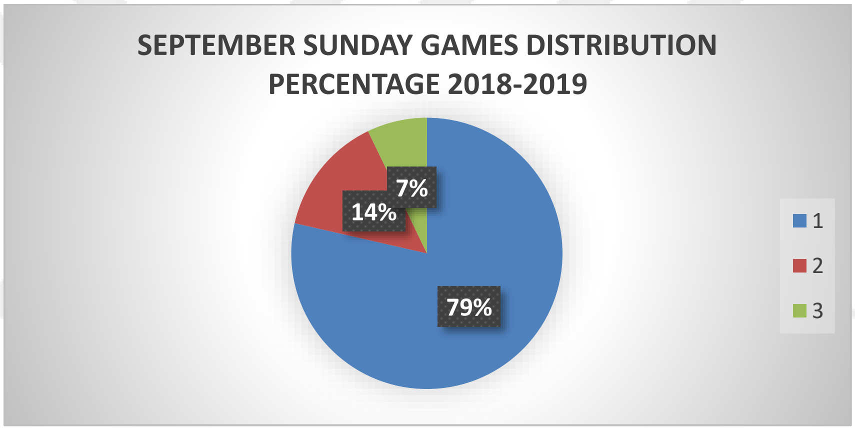

Figure 11: Distribution of Sunday games in September for 2018/2019

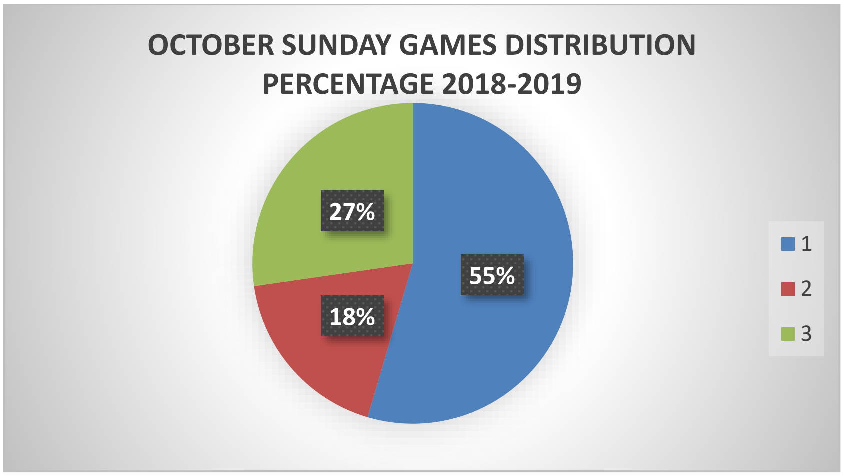

Figure 12: Distribution of Sunday games in October for 2018/2019

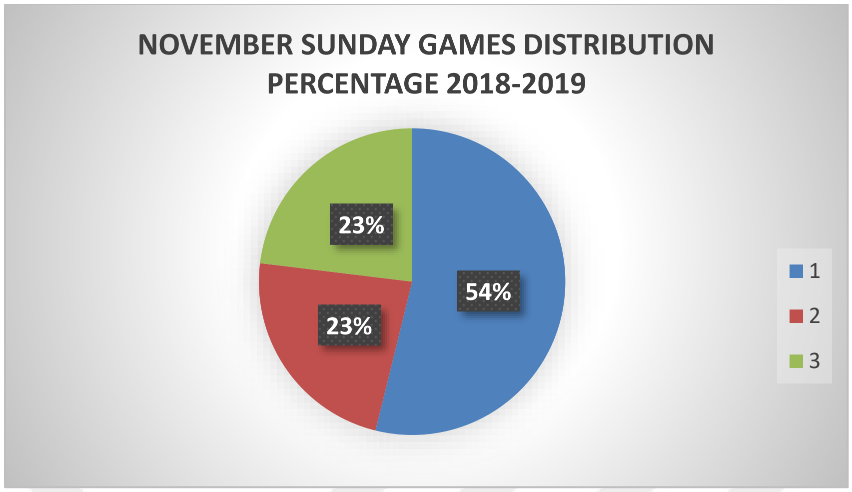

Figure 13: Distribution of Sunday games in November for 2018/2019

Rounds	Friday	Saturday noon	Sat afternoon	Saturday evening	Sunday noon	Sunday afternoon	Sunday evening	Monday
1	1	0	0	3	0	0	4	1
2	1	0	0	3	0	0	4	1
3	1	0	0	3	0	0	4	1
4	1	0	1	3	0	1	3	0
5	1	0	1	2	0	1	3	1
6	1	0	1	2	0	1	3	1
7	1	0	1	2	0	1	3	1
8	1	1	1	2	1	1	2	0
9	1	1	1	1	1	1	2	1
10	1	1	1	1	1	1	2	1
11	1	1	1	1	1	1	2	1
12	1	1	1	2	1	1	2	0
13	1	1	1	1	1	1	2	1
14	1	1	1	1	1	1	2	1
15	1	1	1	1	1	1	2	1
16	1	1	1	1	1	1	2	1
17	1	1	1	1	1	1	2	1
18	1	1	1	1	1	1	2	1
19	1	1	1	1	1	1	2	1
20	1	1	1	1	1	1	2	1
21	1	1	1	1	1	1	2	1
22	1	1	1	1	1	1	2	1
23	1	1	1	1	1	1	2	1
24	1	1	1	1	1	1	2	1
25	1	1	1	1	1	1	2	1
26	1	1	1	2	1	1	2	0
27	1	1	1	1	1	1	2	1
28	1	1	1	1	1	1	2	1
29	1	1	1	1	1	1	2	1
30	1	1	1	1	1	1	2	1
31	1	1	1	1	1	1	2	1
32	1	1	1	1	1	1	2	1
33	1	1	1	1	1	1	2	1
34	1	1	1	2	1	1	2	0
Avg	1,00	0,79	0,91	1,44	0,79	0,91	2,29	0,85

Table 6: Ideal day distribution of games per slot

Taking into account the above visuals and examining the schedules, we see the ideal distribution of games on match days throughout the season. It is shown in Table 6 that except those weeks in which national games are scheduled, all other rounds should follow a distribution of 1-3-4-1. These distributions are then dispersed as 1-1-1 for Saturday and 1-1-2 for Sunday. These mean one game each for Saturday noon, Saturday afternoon, and Saturday evening. Likewise, Sunday noon and Sunday afternoon have one game each then two games on Sunday evenings. Friday and Monday have 1 slot apiece. We see that the first eight weeks did not follow this distribution because as mentioned earlier and represented in the figures above, early season fixtures are done generally in the evening.

After examining the available data and related charts, we will now explain the methodology to be used for this study in the next section.

4. METHODOLOGY

The main methodology used in this thesis work is about the well-known just-in-time (JIT) concept. As popularly known, just-in-time is a method used in minimizing waste and reducing inventory and is a major philosophy used by the Japanese. The whole concept of this method revolves around providing maximum efficiency while ensuring minimum waste rate in a production line. To give it a more precise definition, JIT is a philosophy of scheduling or arranging the correct items of ideal quality in the right amount at the right time in a specific place. The renowned automobile manufacturers Toyota were the first to implement this method in order to satisfy customer demands with minimal delay and is known to be an efficient method [27]. Although the JIT is a wide concept consisting of interrelated elements such as inventory management, quality management, production waste reduction etc., our focus will be on the assembly of items.

Since JIT aids in the minimization of time lapse between processing times of particular items, it brings a lot to this work in the sense that the day distribution of games played on the weekends will be scheduled to specific time periods of the day based on the previous schedules for each team. An extension of JIT under scheduling mixed models assembly lines called Monden heuristic will be used as an inspiration towards the formulation of our problem. Mixed model assembly entails deciding the cycle time of the line, the number and sequence of stations on the line, and balancing the line. The mixed model approach also entails deciding the order in which goods will be scheduled for assembly in order to maintain a consistent work load at each station on the line and avoid exceeding the line cycle time. One of the objectives of JIT is to have, for each item, a fairly constant usage rate as the assembly line approaches its final phase and to achieve that finished items need to be scheduled in a mixed assembly line to ensure a fair usage rate for each component [28]. An analogy can be drawn with case of games scheduling in sports as this work portrays.

Monden proposes a heuristic algorithm for such cases where variations between scheduled end items are reduced. This heuristic allows for the used components to have an actual usage rate close to their average usage rate by determining the order in which each component needs to be assembled with the objective of constructing an ideal assembly line. All potential choices are weighed by adding the squared deviations of the component's actual usage rates to determine which end item schedule to use in the next assembly. The minimum of the summed values is selected for the next assembly. The resulting equation is given as:

$$D_{ki} = \sqrt{\sum_{j=1}^{\beta} (\frac{KN_j}{Q} - (X_{j,K-1}) - b_{ij})^2} \quad (1)$$

where:

D_{ki} = The deviation for sequence number K and for end item i.

β = The number of required components.

K = The scheduling sequence number for current end item.

N_j = The sum of components j required in the final assembly sequence.

Q = The sum of end items to be assembled in the final assembly sequence.

$X_{j,K-1}$= The cumulative number of component j used until K-1 assembly sequence.

b_{ij}= The number of component j required to make one unit of end item i.

The above equation ensures that the deviation of actual usage rate from average usage rate among components is as close as possible to ideal. The fact that our problem entails scheduling of games in a closely distributed manner, this equation paves way for the mathematical formulation of this thesis work. The problem is formulated as a non-linear binary integer programming to schedule weekly football games in order to achieve a fairly distributed match-day throughout the season.

4.1 MATHEMATICAL FORMULATION

As mentioned, the formulation is in the form of a non-linear binary program derived from the Monden heuristic. Essentially, the model will find a better result for each round compared to that of the TFF. Since the Turkish Super League consists of 18 teams, n =18, r = 34. Each round has a total of 9 playing slots; one on Friday, one on Monday, and the remaining slots to be played on Saturday and Sunday. The model will minimize the differences between the total times each team has played on a particular day up until that round. When scheduling, the model examines the playing days and time of each team then for any given day and time, looks for a team with the least number of games in previous rounds at that slot and schedule it if every other constraint is accounted for. In that respect, the models assume an ideal distribution for each team in the 34 rounds of the season and the total games played from Friday through Monday are denoted as (s^*, t^*, u^*, v^*) where $s^* + t^* + u^* + v^*$ = 34. We make sure that the total number of appearances on every day of the week up to a specific round is as similar as possible to an optimal distribution of match days associated with that round, just as we make sure that the use of end items in production closely matches their average usages in the Monden heuristic. As a result, for each team, we calculate a metric that calculates the match day count deviation from an ideal and equal distribution in each round. In addition to the match day distribution, integrating the daily slot enables the model to decide a more accurate day and time distribution. Owing to the fact that the model is dynamic in nature, there will be slight modifications in constraints based on the matches played before or after some matches of a particular round. For illustrative purposes, round 7 of the season is formulated where there are Turkish cup matches before the round and the UEFA matches after that round. The schedules for that round are shown below in Table 7. The decision variables and a complete set of parameters are given next.

Home Team	Home Team Index	Away Team Index	Away Team
Galatasaray	1	17	Erzurum
Trabzon	4	14	Kasimpasa
Alanya	9	18	Akhisar
Besiktas	3	10	Kayseri
Sivas	12	16	Bursa
Goztepe	15	8	Konya
Caykur Rize	11	6	Fenerbahce
Ankaragucu	13	7	Antalya
Basaksehir	2	5	Malatya

Table 7: Round 7 schedules

Decision variables

$$x_{ird} = \begin{cases} 1, & \text{if team i plays in round r on day/period d} \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

Parameters;

i = 1,2, . . . , I where I = 18 (Number of teams)

r = 1,2, . . . ,R where R = 34 (Number of rounds)

d ∈ CD = {Wed, Thur, Fri, Sat1, Sat2, Sat3, Sun1, Sun2, Sun3, Mon, Tue}

w_{d2} : weight assigned to deviation D_{d2} in the objective function where d2 ∈ DS = { Fri, Sat, Sun, Mon}

c_1: weight assigned to the summation of the weighted deviations

c_2: weight assigned to deviation V

a_d:The ideal match day distribution on a given round, d in DS

b_d:The ideal number of games on a given matchday/period per round, d in DS2,

where DS2 = {Fri, Sat1, Sat2, Sat3, Sun1, Sun2, Sun3, Mon}

Here;

$$a_d = \begin{cases} \frac{s^*}{34} & \text{if d = Fri} \\ \frac{t^*}{34} & \text{if d = Sat} \\ \frac{u^*}{34} & \text{if d = Sun} \\ \frac{v^*}{34} & \text{if d = Mon} \end{cases} \tag{3}$$

$$b_d = \begin{cases} e^* & \text{if d = Fri} \\ f1^* & \text{if d = Sat1} \\ f2^* & \text{if d = Sat2} \\ f3^* & \text{if d = Sat3} \\ g1^* & \text{if d = Sun1} \\ g2^* & \text{if d = Sun2} \\ g3^* & \text{if d = Sun3} \\ h^* & \text{if d = Mon} \end{cases} \tag{4}$$

T_{ist} : Set of Istanbul teams having home games in the respective week (r)

$T_{tophome}$: Set of top teams in the league playing at home, where top teams are Galatasaray, Fenerbahce, Besiktas, Basaksehir, Trabzon.

While the parameter definition in (3) helps us calculate the ideal match day distribution up to a certain round for each team, the definition in (4) gives the hourly distribution for those match days of all rounds as already explained. CD is the set of all days on which a potential match takes place whereas DS is the set of days on which the league games are scheduled and DS2 is the set of slots per round of a given schedule. b_d metric will be used in the hourly deviation in addition to the weighted match day deviation. The formulation for round 7 is written as follows:

$$\text{Min } c_1 \text{ x } \sum_{\text{d2} \in \text{DS}} w_{d2} \text{ x } D_{d2} + c_2 \text{ x V} \tag{5}$$

Where;

$$D_{d2} = \sum_{i=1}^{I} [x_{i,7,d2} + \sum_{k=1}^{r-1} x_{i,k,d2} - (7 \text{ x } a_{d2})]^2, \quad \text{d2 in \{Fri, Mon\}} \tag{6}$$

$$D_{d2} = \sum_{i=1}^{I} [x_{i,7,Sat1} + x_{i,7,Sat2} + x_{i,7,Sat3} + (\sum_{k=1}^{r-1} x_{i,k,Sat1} + x_{i,k,Sat2} + x_{i,k,Sat3}) - (7 \text{ x } a_{d2})]^2, \tag{7}$$

d2 = {Sat}

$$D_{d2} = \sum_{i=1}^{I} [x_{i,7,Sun1} + x_{i,7,Sun2} + x_{i,7,Sun3} + (\sum_{k=1}^{r-1} x_{i,k,Sun1} + x_{i,k,Sun2} + x_{i,k,Sun3}) - (7 \text{ x } a_{d2})]^2, \tag{8}$$

d2 = {Sun}

$$\text{V} = \sum_{\text{d} \in \text{DS2}} \left(\frac{\sum_{i=1}^{I} x_{i,7,d}}{2} - b_d \right)^2 \tag{9}$$

Subject to:

Feasibility constraints

$$x_{i,7,Fri} + x_{i,7,Sat1} + x_{i,7,Sat2} + x_{i,7,Sat3} + x_{i,7,Sun1} + x_{i,7,Sun2} + x_{i,7,Sun3} + x_{i,7,Mon} = 1, \quad i = 1,\ldots,18 \tag{10}$$

$$x_{i,7,Thur} + x_{i,7,Fri} + x_{i,7,Sat1} + x_{i,7,Sat2} + x_{i,7,Sat3} \leq 1, \quad i = 1, \ldots, 18 \tag{11}$$

$$x_{i,7,Sun1} + x_{i,7,Sun2} + x_{i,7,Sun3} + x_{i,7,Mon} + x_{i,7,Tue} \leq 1, \quad i = 1, \ldots, 18 \tag{12}$$

$$x_{i,7,Wed} + x_{i,7,Thur} + x_{i,7,Fri} \leq 1, \quad i = 1, \ldots, 18 \tag{13}$$

$$x_{i,7,Mon} + x_{i,7,Tue} + x_{i,7,Wed} \leq 1, \quad i = 1, \ldots, 18 \tag{14}$$

$$x_{i,7,Wed} + x_{i,7,Sat1} + x_{i,7,Sat2} \leq 1, \quad i = 1, \ldots, 18 \tag{15}$$

$$x_{i,7,Thur} + x_{i,7,Sun1} + x_{i,7,Sun2} \leq 1, \quad i = 1, \ldots, 18 \tag{16}$$

$$x_{i,7,Sat1} = 0, \mathrm{i} \in \{\mathrm{GS}, \mathrm{FB}, \mathrm{BJK}, \mathrm{BSK}, \mathrm{TS}\} \tag{17}$$

$$x_{i,7,Sun1} = 0, \mathrm{i} \in \{\mathrm{GS}, \mathrm{FB}, \mathrm{BJK}, \mathrm{BSK}, \mathrm{TS}\} \tag{18}$$

$$\textstyle\sum_{\mathrm{i} \in T_{ist}} x_{i,7,d} \leq 2, \quad \mathrm{d} \in \{\mathrm{Fri}, \mathrm{Mon}\} \tag{19}$$

$$\sum_{\mathrm{i} \in T_{ist}} x_{i,7,Sat1} + x_{i,7,Sat2} + x_{i,7,Sat3} \leq 2, \tag{20}$$

$$\sum_{\mathrm{i} \in T_{ist}} x_{i,7,Sun1} + x_{i,7,Sun2} + x_{i,7,Sun3} \leq 2, \tag{21}$$

$$\textstyle\sum_{\mathrm{i} \in T_{ist}} x_{i,7,k} \leq 1, \quad \mathrm{k} \in \{\mathrm{Sat2}, \mathrm{Sat3}, \mathrm{Sun2}, \mathrm{Sun3}\} \tag{22}$$

$$\textstyle\sum_{\mathrm{i} \in T_{tophome}} x_{i,7,k} \leq 1, \quad \mathrm{k} \in \{\mathrm{Sat2}, \mathrm{Sat3}, \mathrm{Sun2}, \mathrm{Sun3}\} \tag{23}$$

$$x_{i,r,Mon} = 0, \quad \mathrm{r} \in \{4, 8, 12, 26, 34\}, \quad i = 1, \ldots, 18 \tag{24}$$

Assignment constraints (round 7 illustrated)

$$x_{1,7,d} - x_{17,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{25}$$

$$x_{4,7,d} - x_{14,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{26}$$

$$x_{9,7,d} - x_{18,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{27}$$

$$x_{3,7,d} - x_{10,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{28}$$

$$x_{12,7,d} - x_{16,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{29}$$

$$x_{15,7,d} - x_{8,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{30}$$

$$x_{11,7,d} - x_{6,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{31}$$

$$x_{13,7,d} - x_{7,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{32}$$

$$x_{2,7,d} - x_{5,7,d} = 0, \quad \mathrm{d} \in \mathrm{DS2} \tag{33}$$

Additional constraints (round 7 illustrated)

$$x_{1,7,Wed} = 1 \tag{34}$$

$$x_{7,7,Thur} = 1 \tag{35}$$

$$x_{11,7,Wed} = 1 \tag{36}$$

$$x_{13,7,Wed} = 1 \tag{37}$$

$$x_{8,7,Wed} = 1 \tag{38}$$

$$\sum_{\mathrm{d} \in \mathrm{CD}} x_{i,7,d} = 1, \qquad i = 1, \dots, I \;\&\; i \neq \{1, 7, 8, 11, 13\} \tag{39}$$

The objective function in (5) minimizes the two deviations of D_{d2} and V that will ensure that the ideal 1-3-4-1 game distribution per round is preserved while enforcing the hourly distribution constraints in the model. D_{d2} in the objective function ensures that the total number of appearances for any of the teams up until that round is very close to the ideal match days distribution for each round. Similarly, V ensures the minimal deviation from the ideal game day slot distribution for each day of any given round. The fact that Friday and Monday have single slots apiece, their deviation metric is calculated in (6). However, the case for Saturday and Sunday differs considering that they have multiple slots to be played in. Therefore, (7) and (8) respectively, calculate the deviation for Saturday and Sunday match day distributions. (9) in turn, calculates the deviation resulting from scheduling games on particular slots on any given match day of a certain round.

Equations (10) – (24) are feasibility constraints for the model which must be enforced regardless of which round is being played. (10) dictates that for every round, each team must play at exactly one slot from Friday to Monday. Constraint (11) to constraint (16) satisfy the minimum rest between consecutive games. Constraint (11) says any team can have at most one game from Thursday to Saturday. Constraint (12) ensures that each team can have at most one game between Sunday to Tuesday. Constraint (13) ensures the same for Wednesday to Friday while constraint (14) enforces the same constraint for Monday to Wednesday. Since UEFA games and the Turkish Cup games are mostly played in the evening, constraint (15) says if a team plays on Wednesday, that team's next game should be scheduled the earliest on Saturday evening. Similarly, constraint (16) requires that if a team plays on Thursday, that team should be scheduled the earliest on Sunday evening. It is very unusual to see that any of the top teams is scheduled to play in the noon period. For that reason, constraint (17) and constraint (18) ensure that none of the top five teams is scheduled to play in the noon either on Saturday or Sunday respectively. Among the teams participating for that season, except for Istanbul, every other city has exactly one team. Due to security reasons and fixture congestions, scheduling more than one game in the same city can be consequential although there are many instances when two games are scheduled but often not more than that. That constitutes our next set of constraints. Constraints (19) through (21) dictates that for teams with home venues in the same city (in this case Istanbul), at most two games can be scheduled to be played in that city on the same day from Friday to Monday. The set of teams from Istanbul is already defined in the parameters. Although the previous three constraints allow the scheduling of two games in the same city (Istanbul) on the same day, these games must not overlap one another. Therefore, constraint (22) states that even if there should be two games in same city on the same day, those games must not be scheduled at the same time. Constraint (23) entails that for those set of top teams in the league, at most one game can be scheduled to be played at the venue of those teams on the same day at the same time. This means no two teams from the top team five can play at home at the same time on the same day. It customary to see that games are not scheduled on Monday whenever there is an upcoming national game. In fact, all games are scheduled only from Friday to Sunday whenever a national game will be played in the subsequent days. To ensure the enforcement of this, constraint (24) is integrated into the model so that no game will be scheduled on Monday in those weeks with national games.

Constraints (25) to (33) are assignment constraints related to the week in question. Constraint (25) states that for that given round (round 7), if team 1 has a game at some time slot from Friday to Monday, then team 17 must also have a game at that particular time slot. Likewise, if team 1 does not have any game from Friday to Monday at any of the time slots, team 17 must not have a game as well. Similar complementary patterns follow for the rest of the constraints until (33).

To account for UEFA games and Turkish Cup games to be played before/after that round, we inserted constraints (34) to (38). In the days preceding that round, there were Turkish Cup games scheduled for teams 7, 8, 11, 13 whereas the days succeeding the round saw UEFA games for teams 1, 3, 18. Hence, we use the stated constraints. Lastly, constraint (39) enforces that except those teams that play in the UEFA and Turkish Cup competition, every other team must have one and only one game between Wednesday to Tuesday for that given round.

By slightly modifying the constraints depending on additional matches before/after each round, we solve the mathematical model optimally using AMPL through its solver CPLEX. The results from this solver will be discussed in the next section.

5. RESULTS

As mentioned previously, we used data from the 2018-2019 season of the Turkish Super League and made comparison with the obtained result from this model. We assigned the following weights to the objective function parameters: c_1 = c_2 = 1; w_{Fri} = 0.11, w_{Sat} = 0.33, w_{Sun} = 0.44, w_{Mon} = 0.11. The ideal distribution is given as 1-3-4-1 from Friday to Monday. Since we want games to be assigned to slots too, we set e* = f1* = f2* = f3* = g1* = g2* = h* = 1, g3* = 2. The ideal total games on each day throughout the season is set as 5-12-12-5 for Friday, Saturday, Sunday, and Monday respectively.

Team	Team index	Friday	Saturday	Sunday	Monday	Total
Galatasaray	1	7	11	13	3	34
Basaksehir	2	4	10	13	7	34
Besiktas	3	5	10	13	6	34
Trabzon	4	6	13	11	4	34
Malatya	5	4	10	16	4	34
Fenerbahce	6	4	11	11	8	34
Antalya	7	3	13	13	5	34
Konya	8	4	11	14	5	34
Alanya	9	4	11	12	7	34
Kayseri	10	1	17	13	3	34
Caykur Rize	11	3	14	12	5	34
Sivas	12	5	13	13	3	34
Ankaragucu	13	4	12	14	4	34
Kasimpasa	14	5	11	10	8	34
Goztepe	15	5	14	12	3	34
Bursa	16	7	10	15	2	34
Erzurum	17	4	11	15	4	34
Akhisar	18	1	11	15	7	34

Table 8: The day distribution resulting from the manual schedule

Table 8 shows the total games played by each team on each day from Friday through Monday over the course of the 2018-2019 season. We observe that the ideal distribution of 5-12-12-5 is never achieved in any of the rounds with lots of deviations. Furthermore, the deviation from the ideal distribution is somewhat not uniform and this brings about an unfair distribution among the teams. In comparison, we see in Table 9 that although not all the rounds yielded the ideal distribution, the deviation is as close as possible for all rounds and teams. This is further supported by the standard deviation results obtained from both results illustrated in Table 10 and Table 11.

The daily standard deviations for Friday, Saturday, Sunday, Monday can be seen as 1.63, 1.86, 1.59, 1.88 respectively for the manual schedule whereas for the optimal is 0.51, 0.32, 0.59, 0.51 for those four days respectively. While the average standard deviation of the manual schedule is around 1.74, we see a considerably low average of 0.49 for the optimal solution. This yields a result of 72 % improvement over the manual schedule.

Another evidence of the improvement obtained by our solution can be seen in the minimum and maximum value of each day from Friday to Monday. These values show the total times each team play on each day from Friday to Monday. For instance, Galatasaray played a total of seven games on Friday, eleven on Saturday, thirteen on Sunday, and three on Monday throughout the season. However, under the optimal schedule, Galatasaray would ideally play five games on Friday, twelve on Saturday, thirteen on Sunday, and four on Monday. The disparity between the two schedules is apparent. The difference between the maximum and minimum value further illustrates the deviations in both schedules. The average difference under the manual schedule is 6.25 whereas the average difference for the optimal schedule is just 1.25. As a result, 80% improvement is achieved by implementing our model.

Team	Team index	Friday	Saturday	Sunday	Monday	Total
Galatasaray	1	5	12	13	4	34
Basaksehir	2	4	12	14	4	34
Besiktas	3	4	12	13	5	34
Trabzon	4	5	12	13	4	34
Malatya	5	4	12	13	5	34
Fenerbahce	6	4	12	13	5	34
Antalya	7	4	13	13	4	34
Konya	8	4	12	13	5	34
Alanya	9	5	12	13	4	34
Kayseri	10	5	12	13	4	34
Caykur Rize	11	4	12	14	4	34
Sivas	12	4	12	14	4	34
Ankaragucu	13	5	12	13	4	34
Kasimpasa	14	4	12	13	5	34
Goztepe	15	5	13	12	4	34
Bursa	16	5	12	12	5	34
Erzurum	17	4	12	13	5	34
Akhisar	18	5	12	12	5	34

Table 9: The day distribution resulting from the optimal schedule

	Friday	Saturday	Sunday	Monday
Standard deviation	1.63	1.86	1.59	1.88
Maximum value	7	17	16	8
Minimum value	1	10	10	2
Difference	6	7	6	6

Table 10: Day distribution data summary for the manual schedule

	Friday	Saturday	Sunday	Monday
Standard deviation	0.51	0.32	0.59	0.51
Maximum value	5	13	14	5
Minimum value	4	12	12	4
Difference	1	1	2	1

Table 11: Day distribution data summary for the optimal schedule

In terms of the ideal game distribution for each day, for the optimal schedule the desired 1-3-4-1 games allocation is achieved for round 7 as portrayed in Table 12 but the manual schedule has a 1-3-3-2 distribution. One thing to point out though, is the fact that the Sunday games are distributed as one afternoon game and three evening games as opposed to one noon, one afternoon, and two evening games. This is as a result of that round being in the early months of the season when games are not often scheduled at noon time due to weather condition or other reasons best known to the federation.

Home Team	Home Team Index	Away Team Index	Away Team	AMPL Result	TFF Result
Galatasaray	1	17	Erzurum	Sunday evening	Friday
Trabzon	4	14	Kasimpasa	Sunday afternoon	Saturday afternoon
Alanya	9	18	Akhisar	Sunday evening	Saturday afternoon
Besiktas	3	10	Kayseri	Saturday afternoon	Saturday evening
Sivas	12	16	Bursa	Saturday evening	Sunday noon
Goztepe	15	8	Konya	Saturday evening	Sunday afternoon
Caykur Rize	11	6	Fenerbahce	Monday	Sunday evening
Ankaragucu	13	7	Antalya	Sunday evening	Monday
Basaksehir	2	5	Malatya	Friday	Monday

Table 12: Round 7 schedules comparison

The deviations recorded for the optimal schedule in the whole season occurred in seventeen rounds (50% of the entire season schedule) followed the ideal game day and slot distribution. On the other hand, the ideal distribution for game and slot in the manual schedule occurred in only three rounds which is just 9% of the total rounds. The average deviation for the 2018-2019 season in the case of the manual schedule is 3.82 while that of the optimal is 1.24. This is a 68% improvement in terms of weekly deviations. These can be seen in Figure 14.

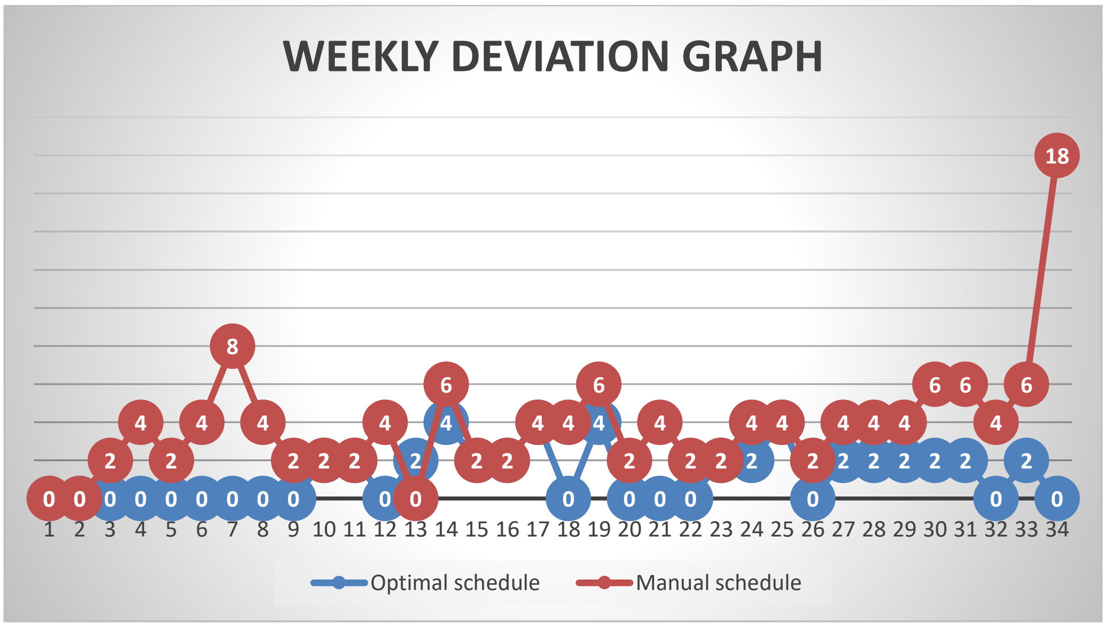

Figure 14: Graph showing weekly deviations for optimal and manual schedules

6. CONCLUSION

Sports scheduling has gained popularity over the years. Teams, organizations and other stakeholders have different objectives with respect to the schedules. That led to several studies to be carried out. This thesis aims to find better schedules compared that of the TFF for the 2018-2019 season. The objective is to minimize deviations from the ideal game distribution throughout the season taking into account some criteria that must be met.

In this study, we formulated the problem as a non-linear binary integer program and solved it using AMPL solver CPLEX. We solved for each week separately to obtain optimum schedule based on the constraints for that week. We assigned a value of 1 to deviations in the objective function and followed the ideal distribution of 1-3-4-1 as preferred by the federation.

Results show that our schedule from AMPL model outdoes the scheduling of the TFF. Matches are distributed as close as possible to the ideal distribution. 72% improvement is achieved by the optimal schedule over the manual schedule in terms of the standard deviation from Friday to Monday. We see that 50% of the optimal schedule rounds follow the ideal distribution as compared to only 9% for the manual schedule. Comparison between the average weekly deviations for both schedules yielded a 68% improvement over the manual schedule.

Outputs indicate that implementing our model will ensure a significant improvement to the schedules done by the TFF. It will also help mitigate the level of uncertainty surrounding the process of scheduling by the TFF as there will be a defined system to follow. It should also be noteworthy that although our focus has been on sports scheduling, our model can also be slightly tweaked to accommodate its implementation to other organizations as far as scheduling is concerned.

Owing to the fact that sports are evolving and risks are increasing, further study may incorporate factors such as risks, breaks, and uncertainties to the model. The aforementioned risks may have to do with the weight values assigned to the deviations. Thus, the choice of weights can be integrated differently to obtain a better result.

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