Aalto University
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Optimizing the Planning of Floorball Match Schedules in Finland

Final Report

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1 Introduction

The Finnish Floorball Federation (in Finnish, Salibandyliitto) is the official floorball governing body and organization in Finland. The Finnish Floorball Federation is responsible for running the floorball series of different age groups and regions, among other things, such as training the official floorball coaches and referees and arranging other floorball related events.

1.1 Background

Most games in the floorball series that the Finnish Floorball Federation hosts are played in minitournament format. Scheduling a series in the minitournament format involves selecting an organizing club and location for each minitournament in addition to scheduling the matches inside each minitournament. The minitournament format lowers the amount of kilometers traveled, and thus costs and travel time, compared to traditional series, where teams play one game at a time in a specific location. The Finnish Floorball Federation is committed to lowering the traveled distances in their Sustainability Program 2026 [1]. The minimization of the traveled kilometers has a big impact on the carbon footprint of the Finnish Floorball Federation. When the traveled kilometers by the teams are minimized, the carbon dioxide emissions are also reduced.

Currently, scheduling of each series in minitournament format is done by hand, which takes a considerable amount of time and resources. This project aims to develop a minitournament scheduling model, which would be used to optimize tournament locations as well as the individual games and game order in the minitournaments. The objective of the optimization is to minimize the traveled distance of teams inside a minitourmanent series, while taking into consideration equality and equity in the distance traveled by the teams.

Previously, the Finnish Floorball Federation has had two bachelor's theses done on floorball tournament scheduling with a slightly narrower scope than our project [2, 3]. Both of the bachelor's theses focus on a single type of series, whereas our aim is to create a more comprehensive model that can be used to plan matches in any region or age category. The theses share the same goal as this project of minimizing travel distance, but do not investigate equality as a central concern. The bachelor's theses offer promising results, suggesting that optimization can be used to reduce the overall travel distance inside minitournament series.

This project has considerable potential for the Finnish Floorball Federation as well as the floorball community in Finland. The impact of a well-working scheduling model would be felt by players and team personnel as well as the employees tasked with scheduling the tournaments. Shorter and more equal travel distances of the minitournaments would make floorball more accessible and attractive for people in general and would offer environmental benefits as well. A scheduling model would also save the time of manual scheduling, and allow workers of the Finnish Floorball Federation more time and energy to concentrate on other important matters. Additionally, the scheduling model could be adapted and shared with other sports associations, and could in that way benefit an even larger group of people.

The outline of this report is structured as follows: In Section 1.2, the objectives of this project are stated. In Section 2, the previous studies in the area of scheduling, and especially sports scheduling, as well as the previous approaches to minitournament scheduling, are discussed. In Section 3, data provided by the Finnish Floorball Federation and tournament software tool TorneoPal is presented. In Section 4, the methods used in the model are covered. In Section 5, the scheduling results and their validation are described. In Section 6, equality in the travelling distances is discussed and the applicable series for the model are described. In Section 7, the project is summarized, and the recommendations for further development of the model are offered. In Section 8, the self-assessment of the project is given.

1.2 Objectives

The main objective of this project is to form a model that constructs optimal schedules for floorball series. The model should choose tournament venues such that the distances traveled can be minimized equally between the participating teams. In addition, the minitournaments should be scheduled so that the time spent by the teams in the tournament, as well as all excess gaps in the hall reservations, are minimized. The final goal is to make a general model that could take into account the individual constraints of different series. Still, we recognize that there are many different restrictions and needs between the series, making it difficult to incorporate them all into our model within the time frame of this course.

In addition to formalizing the model, it would be beneficial to create a final product that the Finnish Floorball Federation could directly use to form the schedules. The product should be simple and straightforward to use.

The final objective is to provide documentation and instructions to support the actual model. The additional instructions enable efficient use of the model. In addition, the documentation helps to understand the logic behind the model and the basis on which it forms the schedules. If a well-performing model suitable for the scheduling problem is found, the documentation would also make it easier to modify the model to possibly be used in other sports that are facing similar scheduling problems.

2 Literature review

The sport scheduling problems lie firmly in the area of operations research, and sports scheduling is a major business [4]. In these scheduling problems, there exist multiple stakeholders, from players and coaches to broadcasting companies. This creates a lot of complexity in modelling all relevant constraints and objectives. Even though it may sound somewhat trivial to schedule a tournament, the increased amount of constraints and requirements makes the scheduling difficult [5]. Literature on the subject suggests that sports scheduling, in general, is considered an NP-hard problem, with significant computational complexity [6]. The problems similar to minitournament scheduling are often solved using linear programming methods, and some using combinatorial optimization techniques [4, 6, 7, 8]. The minitournament location optimization shares also similarities with facility location optimization problems, which are common objectives in cases of healthcare, transport, and the trade sector [9, 10].

The problem of optimizing the minitournament schedule presented by the Finnish Floorball Federation has already been researched in two bachelor's theses done at Aalto University [2, 3]. Koivisto [2] investigated the optimization of floorball schedules in the junior series, which do not use a robin-round format. This kind of series format allows for schedules in which all teams may not face each other the same number of times, but play the same total number of games over the series. The games in these series are divided into multiple minitournaments. To generate the schedule, a two-part integer program was developed. The first phase optimized the tournament cities so that the total distance traveled by all of the participating teams was minimized. In the second phase, the match pairs were defined such that the occurrence of the same fixtures was minimized. The results provided by the model were compared with an actual schedule for one season of the series. With this kind of optimization model, the total kilometers traveled by the teams were slightly reduced.

Paavilainen [3] studied the optimization of floorball schedules in the Men's 3rd Division, which uses a double round-robin format. The games in this series are played in minitournaments that are divided into autumn and spring seasons. The schedules for the autumn and spring seasons were constructed separately by dividing the optimization problem into two parts. The objective was to minimize the total kilometers traveled by the participating teams. The problem was solved by integer programming. Compared to match programs made by hand, the results provided by the model offered a significant improvement in the minimization of total kilometers traveled. However, some teams located further from the others had an increase in their travel distances.

The previous bachelor's theses on the subject provide a good insight into our problem. However, both of them focused only on specific types of series. The goal of this project is to provide a more general model that could be applied to multiple different series. Additionally, these previous models considered only the determination of tournament cities and match pairs. In our model, the goal would also be to construct and optimize the schedules inside the minitournaments. There could also be further constraints added to consider, for example, the equality of the traveled distances between different teams.

Even though the two bachelor's theses concentrated on minitournament scheduling, organizing a tournament or a league in a minitournament series is not common in the literature. Nurmi et al. [6] developed a framework for scheduling the Finnish national youth ice hockey league, which features both traditional home-and-away matches and minitournaments. The league comprises 15 teams that participate in a triple round-robin tournament. This tournament includes five minitournaments, each featuring six teams, with each team competing in two minitournaments.

The scheduling problem is complex, involving multiple hard and soft constraints, such as ensuring an equal number of home games for each team. To generate a schedule, the method involves solving four distinct combinatorial problems, aiming to avoid violations of hard constraints while minimizing the sum of soft constraint violations. The algorithm used to tackle these subproblems employs a greedy hill-climbing mutation (GHCM) heuristic, which seeks to move toward more attractive solutions. If the algorithm becomes stuck in a region of non-optimal solutions, it shuffles the current schedule to explore other possibilities. While the algorithm does not guarantee an optimal solution, it is sufficient to create a schedule that meets the necessary constraints.

Other scheduling problems that do not involve minitournaments are far more common in the literature. Knust [8] studied the scheduling of a non-professional table-tennis tournament with time relaxation and double round-robin format. This task was encountered with integer linear programming (ILP) and multi-mode resource-constrained project scheduling problem approaches. With the latter approach, they divided the scheduling problem into two stages, which were visited iteratively until the optimal solution was found. In the first stage, so-called home-away assignments were optimized, and in the second stage, the schedule was optimized based on the first stage. Both of the approaches provided efficient results.

Ribeiro [4] reviewed sports scheduling problems discussed in the literature. The three fundamental problems arising from sports scheduling were stated and formulated, and approaches to tackling different scheduling problems in the most common sports were discussed. Integer programming, constraint programming, and meta-heuristics were stated to be commonly useful methods to tackle these kinds of problems. Regarding to our problem, it was also recognized that the optimization problem (break minimization) can be divided into two subproblems that can be solved sequentially.

Dimitsas et al. [7] created an algorithm to solve a sports scheduling problem introduced in the International Timetabling Competition 2021. The problem is to find an optimal schedule for a double round-robin tournament, which has both soft and hard constraints. Hard constraints are mandatory to satisfy, while the dissatisfaction of a soft constraint induces a penalty in the objective function. An initial solution involving only the base constraints is formed using the CP/SAT solver, which reformulates the constraint programming model into a satisfiability model.

In the next phase, the soft constraints are ignored, and the hard constraints are considered as soft constraints. An attempt to satisfy the constraints is made by using simulated annealing, which is an optimization method that accepts inferior solutions with a certain probability to avoid getting stuck in local minima. If the constraints are satisfied, the hard constraints are enabled, and the soft constraints are activated. Simulated annealing is performed again to obtain an optimal solution to the initial problem.

Rasmussen [11] studied the scheduling of the Danish soccer league, which follows the triple round-robin format. In the Danish soccer league, there are numerous constraints making the problem computationally hard. The scheduling is approached with logic-based Berders decomposition, with which the problem is divided into a master problem to find a sequence of home and away games for teams (pattern set) and a subproblem to find a schedule for that pattern set. The algorithm first generates a pattern for the tournament that is divided into two parts. Then the teams are assigned to patterns with an integer programming model. Next, the algorithm checks for feasibility and then constructs the schedule. The algorithm provided feasible results for different randomly generated instances, but for only one instance the optimality was proven. The time limit for the model run was 1800 seconds in the study.

The problem of game location selection can also be applied to facility location optimization problems. Our problem closely resembles the p-median facility location problem. In this type of problem formulation, a number of p facilities are placed optimally based on demand locations and metrics for optimality. In the article by Digehsara et al. [9], equity between demand notes is emphasized in solving the p-median facility location problem, and later applied to a case study on Vancouver Metro, a federation comprised of 23 authorities in the Vancouver metropolitan area.

In our problem, the home facilities of each team represent the demand nodes in a p-median facility location problem setting, and the facilities to be located are the sports arenas where the minitournaments will be played. Equity is highlighted in our problem, since where optimal setting of tournament locations minimizes the overall travel distance of the teams, the disparity between the travel distances of individual teams is to be taken into consideration. In their article Digehsara et al. [9] suggest that distance metrics of different kinds of pairwise differences could be used to quantify and minimize the disparity between the demand nodes. Additionally, the authors apply robust optimization to combat the demand uncertainty in the problem, and apply two types of column-and-constraint generation algorithms to solve the mixed linear programming problem.

In addition to the p-median facility location problem, our problem setting can also be considered from the viewpoint of an (uncapacitated) warehouse location setting, which is a well-known combinatorial optimization problem. In (U)WLP, the goal is to place n warehouses that minimize the fixed costs of the warehouses and transportation costs between the warehouses and the stores. The distances between stores and warehouses are calculated by assigning each store to its closest warehouse.

A simple yet efficient method for solving the (U)WLP is illustrated in an article by Michel and Van Hentenryck [10]. Tabu search is a metaheuristic optimization algorithm, and is generally used for combinatorial optimization problems in transportation optimization. The algorithm starts with an initial solution and searches the neighbourhood to find the optimum. The neighbourhood of a solution is defined as the solutions obtained by making a small change to the current solution. Additionally, the tabu search implements a list structure that keeps track of forbidden "moves" to avoid cycling between explored solutions. The best solution of the neighbourhood is chosen as the next candidate, and the algorithm stops when a specific stopping criterion is satisfied. In the article, the simple tabu search algorithm is compared to a branch and bound algorithm and a genetic algorithm, and is shown to be, in general, faster while still producing optimal results with high frequencies.

3 Data

3.1 Data provided by the Finnish Floorball Federation

The Finnish Floorball Federation has provided us with background materials on minitournament series scheduling. These materials are in the .xlsx format and contain previous schedules of the series and information about specific restrictions relating to the series. The material contains some junior series in South Finland, some junior series in West Finland, and some Men's 3rd Division series. These materials are used for constructing and validating the models. In Figure 1, an example schedule of the first two rounds (in this case, 4 minitournaments) of Group A in Men's 3rd Division in South Finland can be seen. In this specific series, there are 10 teams from 9 different cities. The most important part of the materials is the info-section, which contains the information about the rules and restrictions of the series.

sarja	lohko	ottelu	pvm	klo	Kotijoukkue	Vierasjoukkue	kenttakoodi	kenttanimi	kierros	Vastuujoukkue	
424	A		30.09.2023	11:00	Obelix	Jäppärä	999945002-1	1		Obelix	Saimaa Stadiumi
424	A		30.09.2023	12:30	PuU	Pelicans SB II	999945002-1	1		Obelix	Saimaa Stadiumi
424	A		30.09.2023	14:00	Jäppärä	StU	999945002-1	1		Obelix	Saimaa Stadiumi
424	A		30.09.2023	15:30	Pelicans SB II	Obelix	999945002-1	1		Obelix	Saimaa Stadiumi
424	A		30.09.2023	17:00	StU	PuU	999945002-1	1		Obelix	Saimaa Stadiumi
424	A		01.10.2023	10:00	Pesupallo	Snato	379618082-1	1		Pesupallo	Liikuntakeskus Areena
424	A		01.10.2023	11:30	Butchers IBK	HoSB	379618082-1	1		Pesupallo	Liikuntakeskus Areena
424	A		01.10.2023	13:00	Snato	Sudet SB II	379618082-1	1		Pesupallo	Liikuntakeskus Areena
424	A		01.10.2023	14:30	HoSB	Pesupallo	379618082-1	1		Pesupallo	Liikuntakeskus Areena
424	A		01.10.2023	16:00	Sudet SB II	Butchers IBK	379618082-1	1		Pesupallo	Liikuntakeskus Areena

sarja	lohko	ottelu	pvm	klo	Kotijoukkue	Vierasjoukkue	kenttakoodi	kenttanimi	kierros	Vastuujoukkue	
424	A		21.10.2023	10:00	Butchers IBK	StU	566261969-1	1		Butchers IBK	Imatran UT
424	A		21.10.2023	11:30	Obelix	Pesupallo	566261969-1	1		Butchers IBK	Imatran UT
424	A		21.10.2023	13:00	StU	Snato	566261969-1	1		Butchers IBK	Imatran UT
424	A		21.10.2023	14:30	Pesupallo	PuU	566261969-1	1		Butchers IBK	Imatran UT
424	A		21.10.2023	16:00	Snato	Obelix	566261969-1	1		Butchers IBK	Imatran UT
424	A		21.10.2023	17:30	PuU	Butchers IBK	566261969-1	1		Butchers IBK	Imatran UT
424	A		22.10.2023	10:00	Jäppärä	Pelicans SB II	999945065-1	1		Jäppärä	Kärkölän lh
424	A		22.10.2023	11:30	Sudet SB II	HoSB	999945065-1	1		Jäppärä	Kärkölän lh
424	A		22.10.2023	14:00	Pelicans SB II	Sudet SB II	999945065-1	1		Jäppärä	Kärkölän lh
424	A		22.10.2023	15:30	HoSB	Jäppärä	999945065-1	1		Jäppärä	Kärkölän lh

Figure 1: Example of data provided by the Finnish Floorball Federation

3.2 Data provided by TorneoPal

To get access to more data, TorneoPal, a partner of the Finnish Floorball Federation, provided access to their API. TorneoPal is a tournament software tool that can be used to record and organize tournaments, which, e.g,. The Finnish Floorball Federation uses to display, record, and communicate series data. From the TorneoPal API, we got the data from previous seasons of different series. Our model also takes inputs from the API.

4 Methods

Scheduling problems are computationally demanding, and there can exist thousands of decision variables in the problems. We tackle this challenge by dividing the mininitournament scheduling problem into subproblems. In this way, the computation times do not increase to a level that the model is not usable for the Finnish Floorball Federation. These subproblems are approached by formulating them as Mixed Integer Programming (MIP) -problems and using a non-commercial solver, HiGHS, to solve them. We utilize the open-source programming language Python and its pulp library, which allows for solving MIP and LP problems.

Since there are many series with different rules, we focus on subsets of series that contain as many series as possible and are solvable with the same model. Thus, we build two submodels that together can solve a large number of floorball series. These two submodels are combined with Python into a one program that decides which submodel to use based on the input values.

The first submodel is based on a model by Paavilainen [3], which was developed for solving the minitournament scheduling problem in the Men's 3rd Division in South-East Finland. This series follows a double round-robin format, which is split into autumn and spring seasons. The series's restrictions and rules are pretty tight, implying that the model developed for solving that series might be too restrictive for solving more relaxed series. This first submodel is presented in Section 4.2, and it is targeted at solving tightly formulated double round-robin series, which include more competitive series, e.g. earlier mentioned Men's 3rd Division.

The second submodel targets non round-robin series that do not have as strict rules as round-robin series. Due to the smaller number of constraints, this submodel is predicted to be computationally more efficient than the submodel in 4.2. This submodel is loosely based on and expanded from the model by Koivisto [2], which was developed for solving the minitournament scheduling problem in the junior series in West Finland. This kind of series format is played mainly in junior series, where the main goal of the series is to get to play floorball, and the competitive aspect is not a priority. This submodel is presented in Section 4.3. The two submodels have the same decision variables, which are presented in Section 4.1.

These two submodels are used to optimize the locations and match pairs of each minitournament. After the optimization of matches, the internal scheduling of minitournaments is completed with a separate script, which is based on readily defined templates. The internal scheduling of each minitournament is independent of the other minitournaments, and it can be done separately for each case. The internal scheduling is similar in both types of series structures, which allows it to be implemented with a single script.

4.1 Decision variables

The first decision variable x_{ijtl} defined in (1) represents a single game in the series. It indicates which teams play against each other. Additionally, it has the information of the round and the location at which the game is played.

$$x_{ijtl} = \begin{cases} 1, & \text{if team } i \text{ plays against team } j \text{ at time } t \text{ in location } l \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

The model for double round-robin series in Section 4.2 considers i as a home team and j as an away team in (1). Locations l are bound to teams and their home venues. Thus, for double round-robin series, x_{ijtl} describes team i (home team) playing team j (away team) in tournament t while team l hosts t at their home venue.

The model for non round-robin series in Section 4.3 does not distinguish between home and away teams. This is because in these more flexible series, it is not necessary to have an equal number of home and away games throughout the season for each team. The division of home and away games inside single minitournaments is done later in the second phase presented in Section 4.4. For this model, the locations l are bound to the clubs and their home venues. Multiple teams from the same club can attend the same series in these less strict series. Thus, for non round-robin series, x_{ijtl} describes team i playing team j in round t while club l hosts t at their home venue.

It must be acknowledged that each round is divided into (mini)tournaments and each club can have either one or multiple teams playing in a single series. When location l is mentioned later in this report, it refers to a team l in the context of double round-robin tournament. In the context of non round-robin tournaments, the location l refers to club l and it's home venue. Analogously, in the context of double round-robin tournaments, time t refers to tournament t and in the context of non round-robin tournaments, it refers to round t.

The second decision variable z_{itl} defined in (2) indicates whether a certain team participates in a minitournament at a given time and location. This variable is needed because games of a single round can be played at multiple venues.

$$z_{itl} = \begin{cases} 1, & \text{if team } i \text{ plays at time } t \text{ in location } l \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

The third binary variable in the model y_{lt} defined in (3) represents the locations in which the minitournaments are played. For the non round-robin series in Section 4.3, the locations in which a minitournament can be held are defined by the home locations of the participating clubs. Thus, this variable also represents the organizing club.

$$y_{tl} = \begin{cases} 1, & \text{if a minitournament is held at time } t \text{ in location } l \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

The model for non round-robin series in Section 4.3 locates the minitournaments during the optimization to clubs, and later, after the optimization, they are assigned to a team representing each club. For the non round-robin model, the time t in each of the constraints (1), (2), and (3) represents the number of the round. A minitournament is uniquely defined by the time t and location (organizer) l.

The model for double round-robin series in Section 4.2 does not distinguish between clubs and teams because games between teams of the same club are not constrained. In addition, the time t represents the number of a minitournament, instead of a round.

These three types of binary decision variables that define the structure of the series have a certain amount of overlap. This could be seen as a problem since generally as the number of variables increases, the optimization becomes computationally more complex taking a longer time to solve. We tried an initial aproach where the model had less variables. However, reducing the number of variables made the constraints more complicated, again increasing the complexity of the model. Thus, we made a compromise with a bit more variables and simpler constraints.

4.2 Submodel for double round-robin series

This submodel schedules the series following a double round-robin format. Each round is divided into two minitournaments in separate locations. Each team plays two matches per round. The series is divided into autumn and spring rounds, where the former has more rounds in case the number of rounds is odd. The number of rounds is one less than the number of teams. Each team has to first face every other team once before facing any team a second time.

The autumn and spring rounds have separate optimization formulations to avoid a larger and more complicated formulation. In addition, it may be computationally more efficient to solve two smaller problem instances. The autumn schedule is utilized for optimizing the spring round to ensure that each team has both a home and an away game against every other team during the season. The decision variables in Section 4.1 are used. Next, we present the objective function and the constraints.

4.2.1 Formulation of the autumn rounds

We define T_a as the set of autumn tournaments. I is the set of all teams. Equation (4) is the objective function, which minimizes the total distance traveled by the teams. D_{il} is the distance from team i's home venue to team l's home venue.

$$\text{min.} \sum_{i}\sum_{t}\sum_{l}(D_{il} + D_{li}) \cdot z_{itl} \tag{4}$$

Constraint (5) prevents a team from playing against itself.

$$\sum_{t}\sum_{l} x_{ijtl} = 0, \ \forall i = j \tag{5}$$

Constraint (6) forces each team l to organize at most one tournament during the autumn round. If the number of teams is even, each team organizes exactly one tournament. If the number of teams is odd, the number of minitournaments is one less than the number of teams. Thus, one team does not organize a minitournament during the autumn rounds.

$$\sum_{t} y_{tl} \leq 1, \ \forall l \in I \tag{6}$$

Each tournament t is organized by exactly one team, according to the constraint (7).

$$\sum_{l} y_{tl} = 1, \ \forall t \in T_a \tag{7}$$

In each round, two tournaments are played. Constraint (8) ensures that each team i plays in exactly one tournament in each round. n_{T_a} is the number of autumn tournaments.

$$\sum_{l} z_{itl} + z_{i(t+1)l} = 1, \ \forall i, t = 1, 3, 5, ..., n_{T_a} - 1 \tag{8}$$

If a tournament t is organized in location l (at the home venue of the team l), the constraint (9) ensures that the team l plays at its home tournament t.

$$z_{ltl} \geq y_{tl}, \ \forall l \in I, t \in T_a \tag{9}$$

Constraints (10) ensure that each team i has one home game in every tournament t they play in. Analogously, the constraint (11) makes sure that each team i has one away game in every tournament t they play in.

$$\sum_{j} x_{ijtl} = z_{itl}, \ \forall i \in I, t \in T_a, l \in I \tag{10}$$

$$\sum_{i} x_{ijtl} = z_{jtl}, \ \forall j \in I, t \in T_a, l \in I \tag{11}$$

Constraint (12) constrains the number of teams in a tournament between four and seven. The aim of this is to obtain tournaments of suitable duration.

$$4 \cdot y_{tl} \leq \sum_{i} z_{itl} \leq 7 \cdot y_{tl}, \ \forall t \in T_a, l \in I \tag{12}$$

Constraint (13) ensures that there are no subtournaments inside tournament t. The definition of the existence of subtournaments is that the games of a tournament could be further divided into two or more locations without having to change the teams in matches. This constraint eliminates the subtournaments inside minitournaments of seven or fewer teams. It is assumed that seven teams are the maximum size for a tournament. This assumption is based on the fact that, generally, games of the DRR series start every 90 minutes, and thus, having more than 7 teams would make the tournament days too long.

$$x_{ijtl} + x_{kitl} + x_{jktl} \leq 2, \ \forall i, j, k, l \in I, t \in T_a \tag{13}$$

Next, we present constraints dependent on the number of teams. These constraints ensure that each match pair occurs the right number of times during the autumn rounds and that the division of home and away games is consistent throughout the whole season.

When the number of teams in the series is even, constraints (14) - (17) are applied. The number of autumn rounds for an even number of teams is half the number of teams. More constraints are needed compared to an odd number of teams, because each team has to play one opponent twice during the autumn rounds.

With an odd number of teams, the number of autumn rounds is exactly the same as the number of spring rounds, which is half of the number of teams rounded down. Thus, each team plays once against each opponent during autumn rounds. When the number of teams is odd, the constraint (18) is used.

Constraints for even number of teams

$$\sum_{t=1}^{n_{T_a}-2} \sum_{l} x_{ijtl} + x_{jitl} \leq 1,\ \forall i \in I, j \in I \tag{14}$$

$$\sum_{t} \sum_{l} x_{ijtl} + x_{jitl} \geq 1,\ \forall i \in I, j \in I \tag{15}$$

$$\sum_{t} \sum_{l} x_{ijtl} \leq 1,\ \forall i \in I, j \in I \tag{16}$$

$$\sum_{l} \sum_{t=n_{T_a}-3}^{n_{T_a}} x_{ijtl} + x_{jitl} \leq 1,\ \forall i \in I, j \in I \tag{17}$$

Constraint (14) ensures that each team faces every other team at most once before the last round of the autumn, which is the middle round of the season. According to constraint (15), each team faces every other team at least once during the autumn. In other words, constraints (14) and (15) ensure that each team faces only new teams before the middle round, and during the middle round, one new and one previously played opponent is faced. Because in the middle round, one previously faced team is faced again, constraint (16) is needed to make sure that each team has no more than one away and one home game against each opponent. Finally, constraint (17) ensures that the same match pair is not repeated in two consecutive rounds or the same round. It is sufficient to consider only the last two autumn rounds because the previous rounds are taken care of by constraint (14).

Constraints for odd number of teams

$$\sum_{t}\sum_{l} x_{ijtl} + x_{jitl} = 1,\ \forall i \in I, j \in I \tag{18}$$

If the number of teams is odd, the constraint (18) ensures that each team faces each other exactly once during the autumn rounds.

Because there are multiple series with different characteristics, we also have other constraints that are used for series that require them. For example, some teams do not have their own home venue, or some teams share the same home venue, which requires changing the constraints. In addition, some double round-robin series have fewer than nine teams. In that case, the strict constraints in Section 4.2.1 make the problem infeasible. Thus, for those series, we use a slightly modified formulation where each round is played at a single place in one minitournament.

4.2.2 Formulation for spring rounds

The formulation for the spring rounds follows the same outline as that defined for the autumn rounds in Section 4.2.1. The same decision variables, defined in Section 4.1, are used. The optimization results from the autumn rounds are used as input for the optimization of the spring rounds. We define $\hat{y}_{tl}$ as fixed values corresponding to optimal values of the decision variables y_{tl} of the autumn rounds. Similarly, $\hat{x}_{ijtl}$ corresponds to optimal values of x_{ijtl} of the autumn rounds. Next, we present the formulation of the spring rounds. We define T_s as the set of spring tournaments.

$$\text{min.} \sum_{i}\sum_{t\in T_s}\sum_{l}(D_{il} + D_{li}) \cdot z_{itl} \tag{19}$$

$$\sum_{t\in T_s}\sum_{l} x_{ijtl} = 0,\ \forall i = j \tag{20}$$

$$\sum_{t\in T_a} \hat{y}_{tl} + \sum_{t\in T_s} y_{tl} \leq 1,\ \forall l \in I \tag{21}$$

$$\sum_{l} y_{tl} = 1,\ \forall t \in T_s \tag{22}$$

$$\sum_{l} z_{itl} + z_{it+1l} = 1,\ \forall i, t = 1, 3, 5, ..., n_{T_s} - 1 \tag{23}$$

$$z_{ltl} \geq y_{tl},\ \forall l \in I, t \in T_s \tag{24}$$

$$\sum_{j} x_{ijtl} = z_{itl},\ \forall i \in I, t \in T_s, l \in I \tag{25}$$

$$\sum_{i} x_{ijtl} = z_{jtl}, \ \forall j \in I, t \in T_s, l \in I \tag{26}$$

$$4 \cdot y_{tl} \leq \sum_{i} z_{itl} \leq 7 \cdot y_{tl}, \ \forall t \in T_s, l \in I \tag{27}$$

$$x_{ijtl} + x_{kitl} + x_{jktl} \leq 2, \ \forall i, j, k, l \in I, t \in T_s \tag{28}$$

$$\sum_{l} \sum_{t=n_{T_a}-1}^{n_{T_a}} \hat{x}_{ijtl} + \sum_{l} \sum_{t=1}^{2} x_{ijtl} = 1, \ \forall i \in I, j \in I \tag{29}$$

$$\sum_{t \in T_a} \sum_{l} \hat{x}_{ijtl} + \sum_{t \in T_s} \sum_{l} x_{ijtl} = 1, \ \forall i \neq j \tag{30}$$

Most of the constraints are similar to those defined in Section 4.2.1. The objective function defined by Eq. (19) is the same as Eq. (4), but with a different set of tournaments. Constraint (20) is analogous to constraint (5); (22) ⇔ (7), (23) ⇔ (8), (24) ⇔ (9), (25) ⇔ (10), (26) ⇔ (11), (27) ⇔ (12), and (28) ⇔ (13), but with T_s used instead of T_a.

Constraint (21) ensures that each team has at least one home tournament during the season. Constraint (29) is analogous to constraint (17) of the autumn rounds. It ensures that the same match pair does not repeat in two consecutive games. It is sufficient to consider the last round of the autumn and the first round of the spring. Constraint (30) ensures that each match pair i versus j is played exactly once throughout the whole season. This indicates that each team has one home and one away game against each other team.

4.3 Submodel for non round-robin series

The submodel presented in this section is used to schedule the non round-robin series. In this kind of series, the teams do not have to meet each other a fixed number of times, but rather they play a given number of games, allowing for more flexible scheduling. As flexibility increases, the number of possible solutions grows, increasing the importance of optimization.

The non round-robin series are usually preferred, especially among the junior series, where the importance of equality between teams is considered important. This is why, in addition to minimizing the total distance traveled, the model also supports considering the deviation in the distances traveled between teams.

4.3.1 Constraints

The constraints of this model can be formulated with the decision variables in Section 4.1. The constraints can be divided into three different groups. The first group consists of teamwise constraints (31) - (34) and contains the general restrictions posed by the series structure. The second type of constraints modeled in (35) - (39) are defined at a club level. Finally, we have the constraints (40) - (43) needed to include the consideration of equality of distances traveled by the teams. We define I as the set of all teams, L as the set of all locations, and T as the set of all rounds.

Constraint (31) restricts the number of games a team plays each round. A team plays exactly two games in each minitournament it participates in. Furthermore, this constraint binds the variables x_{ijtl} and z_{itl} together. If the team does not participate in the tournament, z_{itl} is set to zero, and the sum of games must also be zero.

$$\sum_{j=1}^{J} x_{ijtl} + x_{jitl} = 2 \cdot z_{itl} \quad \forall i \in I,\, t \in T,\, l \in L \tag{31}$$

During the series, each team can be only at a single location at every given time step since the team can not play in two locations simultaneously. This is modeled with the constraint (32) that defines to which tournament a team is assigned. This constraint, together with the previous constraint (31) ensures that each team plays exactly two games during each round.

$$\sum_{l=1}^{L} z_{itl} = 1 \quad \forall i \in I,\, t \in T \tag{32}$$

The number of locations that a single minitournament can be split to is not directly restricted in this submodel. However, the minimum and maximum number of games per location are defined and they are denoted with η_{min} and η_{max} respectively. The maximum number of games is at most ten because a larger number of games would make the duration of a tournament day too long. The absolute minimum of games in a tournament is four. However, in the case of four teams, at least one team has to have two consecutive games, causing there to be a gap between the games in order for this particular team to have a resting period between games. These kinds of empty gaps in the hall reservations are avoided since they cost additional money to the Finnish Floorball Federation. Thus, in series consisting of more than twelve teams, the minimum number of games per tournament is set to five. This is because with that many teams, it is possible to split the minitournament into two different locations, even with the bigger minimum number of games. The number of games played in a single minitournament is restricted in constraint (33). Furthermore, this constraint links the variables x_{ijtl} and y_{lt} together. If the location does not have a tournament at a given time, y_{lt} is set to zero, and the sum of games must also be zero.

$$\eta_{min} \cdot y_{lt} \leq \sum_{j=1}^{J} \sum_{i=1}^{I} x_{ijtl} \leq \eta_{max} \cdot y_{lt} \quad \forall t \in T,\, l \in L \tag{33}$$

Finally, the constraint (34) restricts the ability to have the same match pair twice in a single tournament or in two consecutive tournaments. This is because in the junior series, the aim is to meet other teams diversely. Additionally, requiring a gap between the possible occurrences of a repeated match pair makes the schedule more fair.

$$\sum_{l=1}^{L} x_{ij(t-1)l} + x_{ji(t-1)l} + x_{ijtl} + x_{jitl} \leq 1 \quad \forall i \in I,\, j \in J,\, t \in T \setminus \{1\} \tag{34}$$

The next set of constraints is defined on a club level. C_i is defined as the club of team i. As stated before, this kind of non round-robin series structure is commonly used in less professional series and often at junior levels. At this level, the number of players is usually high, causing some clubs to have multiple teams in the same series. Additionally, the resources available to teams are more limited. Thus, many of the teams in the same club have, for example, the same coaches. Because of this, some of the decisions are made on a club level. As a result of shared resources, all teams of the same club must play in a single location during each round. This is modeled with the constraint (35).

$$z_{itl} = z_{jtl} \quad \forall\; C_i = C_j,\; t \in T,\, l \in L \tag{35}$$

The next club-based rule is that the teams from the same club should not play against each other. This is motivated by the fact that these kinds of games are often already played in the teams' practices. Each game costs money for the Finnish Floorball Federation, and thus, it is not meaningful to use these limited resources to arrange them. Instead, the games in the series should focus on meeting teams from other clubs. The match pairs consisting of teams coming from the same club are blocked with constraint (36). Since the constraint considers all of the teams coming from the same club, it also restricts having the teams assigned to play against themselves.

$$\sum_{t=1}^{T} \sum_{l=1}^{L} x_{ijtl} = 0 \quad \forall C_i = C_j \tag{36}$$

If the teams come from different clubs, they should, in the vast majority of the series, meet at least once during the series. Additionally, we should try to minimize the number of repeating match pairs. Therefore, each team plays against each other, usually one or two times during the series. However, in some of the series, all of the teams might not need to meet at all, or there may be a larger number of repeated match pairs allowed. This is why the minimum and maximum numbers of times the teams meet are defined as parameters set by the user. They are denoted with

ω_{min} and ω_{max}, respectively. The number of times teams meet is restricted by the constraint (37).

$$\omega_{min} \leq \sum_{t=1}^{T} \sum_{l=1}^{L} x_{ijtl} + x_{jtil} \leq \omega_{max} \quad \forall C_i \neq C_j \tag{37}$$

Despite minimizing the distances traveled, the tournament schedules should be fair to all teams. Therefore, a tournament should be organized at each team's home venue at least once during the series. The teams of the same club share the same home venue. Thus, each team is not required to host a tournament, instead, it is enough that each club hosts at least one tournament. This rule is modeled with constraint (38).

$$\sum_{t=1}^{T} y_{lt} \geq 1 \quad \forall l \in L \tag{38}$$

The final responsibility for organizing tournaments should be assigned to teams instead of clubs. Thus, after optimizing the schedule, the tournaments are distributed to the teams of the organizing club.

For the club to be responsible for a tournament, the teams associated with it need to attend the tournament. The teams are bound to tournaments organized by their club with constraint (39)

$$z_{itl} \geq y_{lt} \quad \forall\ C_i = l,\, t \in T \tag{39}$$

The final set of constraints of this model allows for minimizing the absolute deviation of the distances traveled by the teams. First, in (40), we define a_i as the total distance traveled by a team i.

$$a_i = 2 \sum_{t=1}^{T} \sum_{l=1}^{L} D_{il} \cdot z_{itl} \quad \forall\ i \in I \tag{40}$$

In (40), D_{il} represents the distance from the team i's home location to the tournament venue of club l. The distance is then multiplied by two to get the total distance traveled. To compute the mean absolute deviations, the mean distance traveled is needed. It is defined in (41), where N_{teams} represents the number of teams in the series.

$$\mu_a = \frac{1}{N_{teams}} \sum_{i=1}^{I} a_i \tag{41}$$

Finally, in constraints (42) and (43) b_i represents the absolute deviation of the traveling distance of team i from the mean distance traveled. Two constraints are needed because constraints involving absolute values cannot be directly used in linear programming.

$$b_i \geq a_i - \mu_a \quad \forall\, i \in I \tag{42}$$

$$b_i \geq \mu_a - a_i \quad \forall\, i \in I \tag{43}$$

4.3.2 Objective

The objective of the model is to minimize the total distance traveled by the teams as well as the mean absolute deviation of these total distances. The objective is

$$\text{min.} \sum_{i\,=\,1}^{I} a_i + \lambda \sum_{i=1}^{I} b_i. \tag{44}$$

The parameter λ is defined by the user and defines how much weight equalizing the total distances traveled between teams has on the objective. In the cases where the deviation between teams does not matter, the parameter can be set to zero. For example, if the distances between the teams' home locations are not great, equalizing the total traveled distances is not that important. However, if the teams come from a large area, it can be meaningful to include equality in the model. Including the equality makes the model run slower as the number of variables and constraints grows. Also, the objective becomes more complex. Thus, it is important to consider in each case whether adding the equality really brings additional value.

4.3.3 Application for single round-robin series

The submodel was initially designed to schedule non round-robin series. However, in the final stages of its development, the possibility of adjusting to the needs of a single round-robin series was implemented. In a single round-robin series, all teams meet exactly once during the series. In the case of these kinds of series, the decision variables, objective, and the majority of the constraints remain the same as described in Subsections 4.1, 4.3.1, and 4.3.2. The behavior of a single round-robin series can be implemented by choosing the parameters correctly. For example, the minimum and maximum number of times teams meet during the series are both set to one. However, as all of the teams need to meet each other at least once, the constraint presented in (36), which blocks all of the matches between teams from the same clubs, is replaced with a constraint that only blocks the teams from playing against each other. In addition, if the number of home and away games should be balanced across the season, an additional constraint should be created. After these changes in the constraints, the model becomes applicable also to the single round-robin series.

4.4 Internal scheduling of minitournaments

The models described in Sections 4.2 and 4.3 determine the match pairs and assign each match pair to a minitournament. Next, the order in which the matches are played inside a minitournament is determined. The scheduling inside the tournament days is conducted using ready-made templates that the Floorball Federation has provided. In the templates, the organizing team generally plays in the first and last games of the tournament day. Also, the templates ensure that a team does not play in two consecutive games while still keeping the gap between games reasonably short to avoid unnecessarily long tournament days.

Game	Home team	Away team
1	**Organizing team**	Team 2
2	Team 3	Team 4
3	Team 2	Team 5
4	Team 6	Team 3
5	Team 4	Team 7
6	Team 5	Team 6
7	Team 7	**Organizing team**

Table 1: Template for the internal scheduling of a minitournament with seven participating teams

We have tournament schedule templates for tournament sizes from four to ten teams. In Table 1, the template with seven participating teams is presented. The match pairs assigned to the minitournament are placed recursively in the templates. First, the organizing team's games are placed in their slots according to the template. After placing the organizing team's games, the next two games are placed. In the case of seven teams, we can determine which teams are teams 2 and 7, and thus locate their remaining games as games 3 and 5, as seen in Table 1. This recursive ordering of the games according to the template is continued until all match pairs are assigned to a slot.

The model for non round-robin series defined in Section 4.3 does not determine the home-away pattern of the games. Thus, for these series, the assignment to home and away teams is performed when creating the internal schedule of the minitournaments. The procedure is otherwise similar to the one described earlier, but in the first game of the tournament, the organizing team plays the opponent, which has a smaller distance to the organizing team's home venue. After this, the rest of the games are ordered following the same procedure, while determining the home and away games according to the templates.

The ready-made templates cannot be utilized if a minitournament has subtournaments, i.e., the participating teams can be divided into separate subtournaments, where teams play only against teams in that specific subtournament. The occurrence of subtournaments cannot be fully prevented in the optimization phase for all series due to the increase in computational time induced by the constraints eliminating subtournaments. If there are subtournaments, each subtournament's games are first scheduled using the ready-made templates. After that, the separate subtournaments are ordered by first taking the first game of each subtournament, then the second game of each subtournament, etc. If one of the subtournaments contains the organizing team, the first game of the minitournament is from that tournament.

5 Results

The model is validated with two different series: a group in Men's 3rd division and a group in Women's 4th division. The results are evaluated for four different seasons of the Men's 3rd division. The solution of a single season of the Women's 4th division is examined more closely with teamwise traveled distances. In addition, an arbitrary series is constructed to demonstrate the performance of the equality consideration in the objective function (4.3.2).

5.1 Men's 3rd Division in South-East Finland

Men's 3rd division in South-East Finland is played in a double round-robin format. Each round, the games are split into two minitournaments played in different venues. In the first four rounds, no team plays against the same opponents, and during the fifth round each team faces one new team and one it has already played against. In this way, the series is split into autumn and spring seasons. The participating teams vary between seasons.

Table 2 shows the realized total distance traveled by the teams, the total distance of the solution provided by our model, and the improvement in traveled distance for different seasons. Our model was run with a time limit of 2500 seconds for both autumn and spring. The model provides a solution with smaller total distance three times out of four. For example, in season 2019-2020, the improvement is over 2500 km, or about 15%. For season 2020-2021, our model's solution results in more distance traveled. However, the realized schedule does not comply with as strict constraints as our model. For example, some match pairs are played with the same home and away team twice during the season. In general, it is hard to find a schedule that satisfies the strict constraints by hand. Overall, the results for this series imply that the model is useful when scheduling double round-robin series into minitournaments.

Season	Realized distance (km)	Solution (km)	Improvement (km)
2018-2019	14517	14007	510
2019-2020	17228	14677	2551
2020-2021	13061	13504	-443
2023-2024	14334	13029	1305

Table 2: Results of Men's 3rd Division at South-East Finland with benchmarking to different realizations.

5.2 Women's 4th Division Group A in South Finland

Women's 4th Division Group A in South Finland is played in minitournaments following double round-robin format. In the season 2024-2025, 11 teams participated in Group A. The kilometres travelled by the teams and the distance provided by

Team	Realized distance (km)	Optimized distance (km)
Blackbirds III	1376	716
FBC Raseborg II	1407	1477
GrIFK	843	795
HaHy	2060	2295
Hawks III	713	191
Loviisan Tor	1368	1014
Pauhu	710	191
SB-Pro III	943	501
SCH II	1110	1099
Team Botox	849	374
ÅIF II	1278	534
Total	12657	9185

Table 3: Realised kilometers compared to the from Women's 4th Division South Finland Group A in the season 2024-2025.

our model can be seen in Table 3. The solution of the model resulted in 9185 km of travelling distance, which is significantly less than the realized traveling distance. In addition, the teamwise distances of almost every team decreased when using the model. Only teams HaHy and FBC Raseborg II travel more in the solution provided by the model compared to the realized travel distance. However, these teams had the most traveled kilometers in the realized series. This is an example of how minimizing the total traveling distance over all teams in a series may punish the teams that are the farthest away. This is because optimally the tournaments are organized in central positions with respect to the teams in the series, meaning that teams farther apart are not ideal tournament organizers.

5.3 Taking into account the equality of the traveling distance between teams

To take into account the teams that are farthest away from the other teams in a series, an equality term can be added to the objective function to penalize for the mean absolute difference in the traveling distances between the teams, as in Equation (44) discussed in Section 4.3.2. To test the differences of the solutions between excluding and including the equality term, the model was run for an arbitrary series with both options.

First, the parameter λ in (44) was set to zero and then to two in order to include the consideration of equality. The results can be seen in Table 4. Penalizing the differences in the traveling distance forces the traveling distances closer between teams, and consequently, the total traveling distance over the teams in the series becomes higher. The increase in the distance traveled varies greatly between teams. For example, the distances of Welhot P13 Rocks, Welhot P14 Rocks, Oupa and Rökäletappio were more than doubled when the equality consideration was added. These teams were also those that originally had the smallest distances traveled. Most of the teams had a smaller change in their traveled distances. In total, the distances increased for twelve teams and decreased only for four teams. The distances that were reduced were also those that were originally the largest.

When incorporating equality of traveled distances as a factor in the objective function, careful consideration must be given to its weight relative to minimizing the total traveled distance. This is because emphasizing equality in the objective may lead to a substantial increase in total travel distance, which could outweigh the potential benefits gained in terms of fairness. Therefore, it should be evaluated in which series the inclusion of equality is justified. For instance, prioritizing equality may be more beneficial in series where travel distances are long and unequal.

Team	Location	Kilometers ($\lambda = 0$)	Kilometers ($\lambda = 2$)
Papas II	Kajaani	2019	1507
Josba pun	Joensuu	1201	1516
LeBa-96	Kontiolahti	1052	1490
Varta musta	Varkaus	1113	1286
Varta valkea	Varkaus	1113	1286
Welhot P13 Rocks	Kuopio	671	1564
Welhot P14 Rocks	Kuopio	671	1564
FBI	Iisalmi	1167	1468
Into musta	Lieksa	1524	1360
Into punainen	Lieksa	1524	1360
Kaiku	Kaavi	462	1465
Oupa	Outokumpu	608	1475
Rökäletappio	Siilinjärvi	664	1568
Top Team Keltainen	Savonlinna	1673	1552
Apassit musta	Nilsiä	920	1370
IisKi	Suonenjoki	1142	1473
Total		17523	23304

Table 4: Comparison between a solution with ($\lambda = 2$) and without ($\lambda = 0$) penalizing for deviations of traveled distances between teams in the objective function

5.4 Trade-off between optimality and runtime

Scheduling a series is a highly constrained problem requiring a lot of computational power. For example, finding an optimal schedule for a double round-robin series with ten teams can take over 10 hours with our model. We tried solving two double round-robin series to optimality by allowing the solver to run for a longer period. The results and the comparison to earlier solutions are shown in Table 5.

Series	Solution with practical runtime			Solution with longer runtime		
	Dist. (km)	Runtime (min)	Dual gaps (%)	Dist. (km)	Runtime (min)	Dual gaps (%)
Men's 3rd div, South-East, 23/24	13029	84	6.33, 14.83	12816	720	2.85, 11.3
Women's 4th div, South, 24/25	9185	84	2.02, 7.41	9151	365	0.01, 4.78

Table 5: Comparison of solutions with different runtimes

As seen in Table 5, the runtime of 84 minutes is not enough to provide optimal solutions for double round-robin series of 10 teams (Men's 3rd div.) and 11 teams (Women's 4th div.). When allowing longer runtime (6 hours per autumn and spring rounds) for the Men's third division, a better result is obtained. However, the solution is still not optimal, as seen from the dual gaps 2.85% for the autumn round and 11.3% for the spring round. The dual gap is the difference between the objective value of the best feasible solution found and the objective value of the best bound provided by solving the dual problem.

Analogously, the solution for the Women's fourth division improved when allowing the solver to run 4 hours per autumn and spring rounds. The autumn round reached optimality, while the dual gap of the spring round remained 4.78%. It should be noted that the optimal solution may not be found by solving the autumn and spring rounds to optimality separately because their solutions are dependent. Solving the autumn round to optimality might worsen the solution of the spring round.

Scheduling a single series for hours might not be feasible considering the large number of different series and the minor improvements in the total distance. Thus, we prioritise the runtime. As a result, we cannot always guarantee that the schedules produced are optimal. However, in practice, a high-quality solution found in significantly less time is often more desirable than waiting for a fully optimal one.

6 Discussion

6.1 Improvement in the quality of schedules produced

One of the major advantages of the final model constructed is that the generated schedules always satisfy all the constraints specified by the Finnish Floorball Federation. Previously, schedules were constructed manually, which made it challenging to even produce a feasible solution that meets all the requirements set. Finding the solution manually involves trying out multiple combinations, which can be time-consuming especially for people with less experience in forming the series. To reduce the scheduling efforts, some of the not so critical constraints were occasionally relaxed in the final schedules made by the employees. For example, in some of the realized double round-robin series, the home-away balance was not always preserved accross all match pairs. In some of the cases the same team was set as a home team in both of the games played during the series. In contrast, our model ensures that all constraints are met thereby improving the quality and fairness of the schedules.

6.2 Equality between teams versus total distance minimization

A term equalizing the distances in the objective function might raise the overall traveled kilometers, which might have a significant impact on individual teams' and players' motivation to play. For example, let us look at a junior team and its players traveling hundreds of kilometers a year more than other teams in the series. This extra traveling might lower the playing motivation of these junior players and get these young players to try out some other hobbies that involve less traveling. Thus, maximizing equality can be tricky and in contradiction with the minimization of kilometers.

As shown in Section 5.3, for series with high disparity of traveled distances, equalizing the distances did drastically increase the kilometers of more teams that it decreased the kilometers of others. Thus, it is justified to argue that penalizing unequal schedules with sum of absolute deviations is not suitable in these series. A more subtle approach for taking into account the equality of traveling distance could be performed by only punishing large deviations between the traveling distances of teams in a series. Thus, the increase in overall traveled kilometers would not be as high because the model would not force the distances to be similar between teams but rather punish large deviations from the mean. This kind of approach was not studied in this project and could be a direction for future work.

In addition to these conclusions, the Finnish Floorball Federation expressed the importance of making the federation as climate friendly as possible in the long run. This further solidified the decision of not including the equality constraints, as they would most likely increase the total travel distance of the teams in the federation. The climate ambitions are also stated in the sustainability program of the Finnish Floorball Federation [1].

6.3 Applicable series for the models

The first submodel presented in 4.2 supports all double round-robin series where all teams play twice against each other. The other submodel presented in 4.3 can be used for series with a more flexible form. In these series, teams do not meet a fixed number of times. The submodel takes as additional input parameters the number of rounds played, the minimum and maximum number of times teams meet during the series, and an indicator describing whether the teams from the same club play against each other or not. These parameters can be modified to meet the needs of most of the non round-robin series. Additionally, the more flexible model applies to single round-robin series where each match pair is played exactly once.

The double round-robin series is the most common serial structure, which is why its scheduling was implemented separately. The other submodel was designed to support the remaining series. However, there still are several series with structures not supported by the model. There are individual series that have unique rules. To list a few, there are quadruple round-robin series and series where the teams first play a double round-robin series, followed by two additional games that are randomly raffled. In a big picture, to construct a more general model, it would be beneficial for the Finnish Floorball Federation to streamline and standardize the series rules in order to develop general model.

Currently, the tournaments are scheduled manually by the employees of the Finnish Floorball Federation, making it easier to implement unique series structures. However, within the scope of this project, designing the model to automatically adapt to all of these exceptions was not a realistic goal. Even though the model is not able to perfectly solve all of these more complicated series, it can still be used to form an initial solution that can then be manually modified further.

7 Conclusions

This project has examined and implemented the optimization of the planning of floorball match schedules in Finland. The work was conducted as a course project at Aalto University in collaboration with the Finnish Floorball Federation.

Sports scheduling as an optimization problem is known to be complex due to its combinatorial nature and large constraint spaces. Especially, as the sizes of the optimized series grow, the computational complexity increases rapidly. Many of the problems covered in the literature of sports scheduling have been shown to be NP-hard problems. Additionally, the structures of desired schedules vary greatly between different sports and levels of professionalism, making the field very diverse.

In this project, our goal was to formulate a model that could divide a floorball series into multiple minitournaments and optimize their match pairs and internal scheduling of games. The main objective of the model formulation was to reduce the manual labor done by the Finnish Floorball Federation by providing a model capable of automatically producing feasible schedules according to the needs of different serial structures. Additionally, the goal was to minimize the distances traveled to the minitournaments by the teams. The motivation for this was to reduce travel costs, time spent on commutes, and the carbon footprint of the series. The final objective was to optimize the internal scheduling of minitournaments to minimize the time spent at the venues, as well as the gaps in reservations. So in general, the goal of this project was to minimize the logistical and financial burden of the series while keeping participation accessible to teams. The final model was created methodically with a focus on the formulations and requirements provided by the client.

The project was carried out successfully, achieving its main objectives. The model formed as a result of the project is capable of producing schedules for the given series, reducing the need for manual work. The schedules produced meet all the requirements set by the Finnish Floorball Federation. With a manually constructed series, some of the less important constraints seemed to be occasionally relaxed. In addition, as presented in Section 5, by optimizing the minitournament locations and teams participating in them, the model was able to reduce the total distances traveled by the teams. The minimization of gaps and the time spent at the venue by the teams was obtained by formulating optimal schedules for minitournaments.

The main challenge the original problem formulation posed was that there are a great number of different serial structures played in the series under the Finnish Floorball Federation. As a result of limited resources and time, not all types of series are included in the model formulated as a result of this project. However, the most central and common types of series, double round-robin series and more relaxed series, were identified and included in the model. Although the model does not fully support all series types, it can be used to produce a preliminary solution that can serve as a basis for further manual adjustments or refinements.

This project was a continuation of the previous work conducted in the two bachelor's theses, considering subproblems of this topic [2, 3]. The main improvements were that the model produced as a result of this project can schedule series for multiple different regions, numbers of participating teams, and serial structures instead of focusing on a single subproblem. The model is also capable of splitting the minitournaments so that the games of a single round can be played simultaneously in multiple locations. Additionally, the project included consideration of equality between distances traveled by teams and provided the internal scheduling of the minitournaments. There were also multiple constraints added to consider limitations caused by the serial structures and better match the needs of different series.

Another major improvement was that the model was adapted into a format that supports easy adoption and is based entirely on open-source software that the Finnish Floorball Federation can independently utilize. Additionally, the model is connected to the API of the software that contains the information of each series and the teams participating to them. These characteristics, together with the detailed documentation, enable the Finnish Floorball Federation staff to run the model themselves without external help.

Although multiple improvements were obtained, there is still room for further development of the model. With sufficient resources, it could be expanded to handle the rest of the serial structures used. This would however also require improving the quality of the data available. For example, the data did not provide rules for all of the series making it hard to know what kind of serial structure they have. Thus, it was also impossible to shape the model to cover these series. Additionally, the home locations and other data was missing for many teams. This made automating the model harder since the data has to be filled in manually. The efficiency of the current model could also possibly be increased through the adaptation of heuristics instead of full optimization. Additionally, different approaches to implementing the equality of the distances traveled between teams could be investigated since the current approach was shown to increase the overall distances significantly. All in all, even though there is always room for further improvement, the model is functioning well and offers the desired capabilities for automating and optimizing the schedules reducing the manual labor of the Finnish Floorball Federation and increasing the quality of the formulated series.

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8 Self Assessment

8.1 How closely did the actual implementation of the project follow the initial project plan?

The project largely followed the initial project plan, but there were some unforeseen challenges that led to some deviations from the original scope.

The project aimed to "create a more comprehensive model that can be used to plan matches in any region or age category." When the vast variety of different series types was identified, the scope of the project was narrowed to only double round-robin and non round-robin series. However, after further exploration, we found that a quadruple round-robin can be constructed using two double round-robin series, and a triple round-robin can be split into a double and a single round-robin. Thus, scheduling these types of series is possible with our model, though it is expected that future development will enhance the program's ability to deal with these formats directly.

The model is now at a stage where by small developments and training of the staff, it can be integrated into the scheduling workflow. However, it is expected that setting up the software and training staff to use the model will require some initial time and troubleshooting. Once this process is complete, the model will reduce the manual labor currently involved in scheduling.

In addition to the major tasks listed in the initial project plan, there were some additional activities, such as:

- Meetings with stakeholders (e.g., Pr. Ahti Salo, Floorball Federation representatives, and TorneoPal developers)

- Expert interviews with professionals like Cimmo Nurmi from Satakunta University of Applied Sciences and Swedish Floorball Federation representatives

These additional activities provided insightful feedback and information about the industry.

The project adhered to its timeline early on, but there were some delays toward the end. For example, the access to the TorneoPal API was gained at the end of April, which required quick actions to explore more available data. Also, the integration of the models to take inputs from the API took time. Consequently, the model development phase extended into early May, and validation was limited to testing a smaller number of series. To compensate for these delays, an additional "crunch day" was dedicated to finalizing the model and writing the reports on May 4th.

Despite these challenges, the project successfully met its core objectives. While not every goal was fully realized in the timeframe, the project is in a position to save considerable time and effort for the Floorball Federation in the future.

8.2 In what regard was the project successful?

The project was successful in several key aspects, particularly in the development of mathematical models and the impact it had on the Floorball Federation's scheduling process. The project succeeded in building a model that provides meaningful solutions to a real-world problem posed by an external stakeholder, and it was delivered within the scope of available resources and time.

The project built upon previous work by two Bachelor's theses related to optimizing and automating floorball minitournament schedules. One of the key achievements was generalizing the existing models to accommodate the scheduling of different types of series, including round-robin and non round-robin formats. Additionally, we expanded the optimization process to include game scheduling within tournaments, ensuring that matches were ordered optimally to minimize travel and time conflicts.

From the team's perspective, the project was successful in fostering collaboration and ensuring equal participation across all stages. Each group member was involved in all aspects of the project, which allowed for a well-rounded learning experience. Since every team member wanted to participate into technical details of creating an optimization model, the split up for discovering different approaches for the model allowed everyone to deep dive into real-life optimization. The literature review conducted at the beginning of the course, combined with hands-on coding, stakeholder meetings, and expert interviews, allowed the team to apply and adapt previously learned optimization frameworks to a real-world problem.

In addition to the core project goals, the team also identified several opportunities for the client to improve and standardize their processes. These recommendations included improvements in data quality, better documentation of scheduling processes, and standardization of practices across different series. By providing these insights, we helped lay the groundwork for future projects within the Floorball Federation and, hopefully, contributed to the success of ongoing and future optimization initiatives.

8.3 In what regard was it less so?

Although the project resulted in a working model with a user interface that can be operated by an everyday user, we did not manage to implement a graphical user interface (GUI) as part of the project. While the inclusion of a GUI was considered only as a possibility early on, it would have certainly added value from the client's perspective, improving accessibility and user experience.

In addition, there is still room for improvement in the robustness of the final product. While the algorithm can handle more types of series than the models developed in the previous Bachelor's theses, we were unable to achieve the goal of creating a model that can schedule any type of series. Specifically, the extension to triple and quadruple round-robin formats was left as future work and is something that will need to be addressed in subsequent iterations of the project.

8.4 What could have been done better, in hindsight?

One of the key areas for improvement would have been more frequent communication with the client. This would involve ensuring that the client's needs and expectations were clearly understood right from the beginning. For example, more detailed input from the client on model requirements, series prioritization, and specific rules could have been obtained earlier in the process. A well-constructed and prioritized list of series rules would have been crucial. This would have ensured that the project team focused on the most important aspects of the scheduling model from the outset. Because of the lack of a clear understanding of the prioritization, the project group members had differing views and implementations of rules or series types, which wasted some of the time allocated for the project.

One of the key issues that could have been addressed earlier was the timely provision of data. The access to TorneoPal API was got late due to communication and incomplete knowledge of its' possibilities. Providing essential data, such as the types of series and constraints, should have been done sooner to avoid delays. This would have allowed the team to start the modeling process without waiting for critical information, and also made the product a better match for the client's needs.

Additionally, it would have been beneficial to complete the final touches on the code well before the deadline, giving the team enough time to incorporate feedback and make any necessary revisions based on the client's evaluations. This would have allowed more time for client-side review and a smoother iteration process.

Reflecting on the entire process, the main areas for improvement were communication (both with the client and within the team), timely data sharing, and ensuring that the final product was presented in a way that allowed for thorough feedback. By aligning expectations earlier on and providing the necessary information sooner, the project could have been completed more smoothly and efficiently.