

Optimizing Interclub Badminton Competitions: Team Grouping, Multi-League Scheduling, and an Incomplete Round Robin Alternative

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The underlying data, calculations, interpretations, and content of the text are the result of the author's own research. All AI-assisted output was critically reviewed and verified, and the author bears full responsibility for the submitted work.

Foreword

This master's dissertation marks the end of my studies in Business Engineering. Over the course of these years, I developed a strong interest in operations research and mathematical optimization. What makes this thesis particularly special to me, however, is that it allowed me to combine that academic interest with something much closer to my heart: badminton. I have been playing the sport for seventeen years, and I still compete in the very interclub competitions studied in this thesis, making this one of the most enjoyable research topics I could have hoped for.

None of this would have come together without the help of a number of people I would like to thank sincerely.

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Enjoy the reading.

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Abbreviations

ALNS	Adaptive Large Neighborhood Search
API	Application Programming Interface
BV	Badminton Vlaanderen
CSV	Comma-Separated Values
DRR	Double Round Robin
ECM	Epsilon-Constraint Method
EIT	Equalized Incomplete Tournament
F&O	Fix-and-Optimize
FIT	Fair Incomplete Tournament
HAP	Home-Away Pattern
HIT	Handicap Incomplete Tournament
IP	Integer Programming
IRR	Incomplete Round Robin
JSON	JavaScript Object Notation
LP	Linear Programming
MIP	Mixed-Integer Programming
R&F	Relax-and-Fix
SA	Simulated Annealing
SRR	Single Round Robin
STGP	Sport Teams Grouping Problem
TRR	Triple Round Robin
VVBBC	Vereniging voor Vlaams-Brabantse badmintonclubs

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1. Introduction

1.1 Background & Context

Badminton is one of the most popular sports worldwide. According to the Badminton World Federation, a global study conducted in collaboration with Infront and YouGov estimated 384 million active players and a fanbase of 744 million, making badminton the second most played and followed sport across surveyed markets (Badminton World Federation, 2025). The sport maintains significant participation in Flanders, with 21,863 players across 211 clubs (Badminton Vlaanderen, 2024).

Organizing competitions for this extensive network presents complex scheduling challenges. In recent decades, effective sports scheduling has become increasingly important as it directly impacts revenue streams, spectator attendance, and participant satisfaction. Well-designed schedules enhance tournament appeal, ensure fair competition, and optimize resource utilization for both professional leagues and amateur competitions (Nurmi et al., 2015). Among the competition formats organized by Badminton Vlaanderen, the interclub competition is the most complex from a scheduling perspective, as it requires coordinating matches across multiple divisions, venues, and months while respecting a range of organizational constraints.

As the governing body for badminton in Flanders, Badminton Vlaanderen oversees most competitive structures in the region, including interclub leagues and tournaments across various player levels and age categories. This research, conducted in collaboration with Badminton Vlaanderen, addresses three interrelated problems in interclub competition planning. The first is the team grouping problem: assigning teams within each division to competition groups such that total travel distance is minimized. The second is the match scheduling problem: constructing feasible match schedules for all groups that satisfy the organizational constraints of Badminton Vlaanderen while optimizing schedule quality. The third is the evaluation of an Incomplete Round Robin (IRR) format as a structural alternative to the current competition design, in which teams are no longer required to play every opponent in a fixed group but instead select a subset of geographically proximate opponents from the full division pool. By addressing these three problems, the thesis aims to provide evidence-based contributions that improve operational efficiency and inform a potential restructuring of the competition format.

1.2 Interclub Competition Scheduling

Badminton Vlaanderen's regional competitions follow a multi-league format in which groups are predominantly scheduled as time-relaxed Double Round Robin (DRR) tournaments, where each team competes against all other teams in their group twice during the season: once at home and once away. One group operates as a Triple Round Robin tournament due to its reduced size. These competitions span from early September through late April, with the season providing more available play dates than required matches, allowing flexible scheduling across the competitive calendar (Swaenepoel, 2023).

The methodology for forming these competition groups differs between competition levels. For the Liga Competition, groups are composed based on geographical proximity assessed by visual inspection, while for the Provincial Competitions, teams are distributed across groups by lottery, as the provincial boundary already constrains travel distance (Casier, 2025). In both cases, an additional constraint prevents multiple teams from the same club from being assigned to the same group.

The planning process addressed in this thesis is decomposed into two sequential phases. In the first phase, teams within each division are assigned to competition groups through an optimization model that minimizes total travel distance. The resulting group assignments constitute fixed input for the second phase, in which match schedules are constructed for all groups simultaneously. This decomposition reflects the organizational practice at Badminton Vlaanderen, where group composition is finalized before scheduling begins. In addition to optimizing both phases, the thesis evaluates the resulting schedules against the operational schedule produced by Badminton Vlaanderen for the 2025-2026 season, providing a direct comparison between the model-based approach and current practice.

The DRR format requires each team to play against every other team in its group exactly twice. Although group composition can be optimized to minimize total travel distance, this optimization is bounded by the fixed group structure: once groups are formed, each team is obligated to play every assigned opponent regardless of geographical proximity, leaving no flexibility to substitute a distant opponent for a nearer one. This limitation is particularly pronounced when a club enters multiple teams in a single division, as the constraint requiring teams from the same club to be assigned to different groups forces at least one team into a geographically less favorable group, increasing its travel burden.

The key advantage of the Incomplete Round Robin format lies in the freedom of opponent selection it affords. Rather than requiring each team to play every opponent in a fixed group, the IRR model selects a subset of opponents for each team from the full division pool, unconstrained by group boundaries. This freedom allows the model to favor geographically proximate opponents, achieving total travel distances below those attainable under any fixed group partition.

Under the current DRR format, rankings are determined within each group separately, and competitive fairness within each group is structurally guaranteed: every team faces every other team in its group twice. Differences in average team strength between groups within the same division do remain a concern, as teams assigned to a stronger group face a harder path to promotion and a greater risk of relegation. However, this is a between-group disparity that does not affect the internal validity of each group's ranking. Under an IRR format, by contrast, a single division-wide ranking is produced from a schedule in which teams do not all face the same opponents. Strength imbalance is therefore a ranking concern that directly affects the comparability of teams' standings. Opponent strength balance constraints are accordingly introduced as part of the IRR formulation to limit the extent to which opponent selection may compromise competitive equity.

The following research questions guide this thesis:

1. To what extent can an integer programming model for the team grouping problem reduce total travel distance compared to the current group formation practices at Badminton Vlaanderen?
2. Can an integer programming model produce schedules of higher quality than the current operational practice, and what constraints does it provide that the current scheduling process does not?
3. How does the Incomplete Round Robin format compare to the optimized Double Round Robin structure in terms of total travel distance, and to what extent can opponent strength balance be maintained under the IRR format?

2. Literature Review

2.1 Round Robin Tournament Formats

A Round Robin tournament represents a competition format where each team plays against every other team a predetermined number of times. This structure is widely used across different sports as it ensures competitive equity through a balanced distribution of opponents (Li, 2024). The basic variant, known as a Single Round Robin (SRR) tournament, requires each team to meet every other team exactly once. In a league with an even number of teams (n), an SRR typically requires $n-1$ rounds to complete all fixtures (Ribeiro, 2012). Figure 1 illustrates a Single Round Robin tournament with 4 teams. In this graphical representation, teams appear as nodes while the matches between them are depicted as connecting edges.

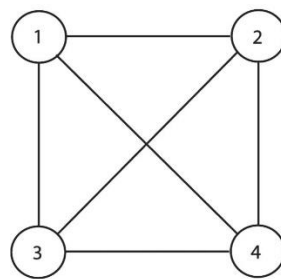


Figure 1: Graphical representation of a SRR tournament with 4 teams (Ribeiro, 2012)

More commonly employed in professional leagues is the Double Round Robin (DRR) tournament, where teams face each other twice, generally once at their home venue and once at their opponent's venue. This format requires $2(n-1)$ rounds for completion when n is even (Kendall et al., 2010). DRR tournaments can be further classified based on their structural implementation. A phased DRR tournament is made up of two intervals, each representing a SRR tournament (Van Bulck et al., 2020). This way a team can't play another team a second time before having played against all other teams at least once. When the ordering of opponents in the second half mirrors that of the first half (with venues reversed), it is termed a "mirrored schedule" (Kendall et al., 2010).

A critical distinction in Round Robin tournament organization relates to temporal constraints. A schedule is classified as "compact" or "temporally constrained" when it utilizes the minimum number of rounds required to schedule all fixtures. In compact schedules with an even number of teams, each team typically plays exactly one match per round without any byes (Li et al., 2023). Conversely, a "time-relaxed" schedule employs more rounds than the minimum required, creating flexibility through the introduction of byes: rounds where specific teams do not compete. As Swaenepoel (2023) notes, this approach is particularly

common in amateur and regional competitions where venue availability and player constraints necessitate scheduling flexibility.

2.2 Compact Round Robin Tournament

The compact Double Round Robin tournament format has received predominant focus in sports scheduling research literature, establishing fundamental concepts and methodologies that inform broader scheduling applications. Understanding these foundational principles provides valuable insights applicable to various tournament structures.

2.2.1 Home-Away Patterns and Break Minimization

The conceptual framework for constructing tournament schedules frequently begins with Home-Away Patterns (HAPs). A HAP represents a sequence specifying whether a team plays at home ('H') or away ('A') in each round. For a viable tournament, a set of compatible HAPs must be generated and assigned to participating teams (Goossens, 2018). A fundamental requirement for HAP set feasibility is maintaining equilibrium between home and away designations within each round. Despite extensive investigation, the computational complexity of determining whether a compatible opponent schedule exists for a given HAP set remains an open question in the literature (Li et al., 2023). A potential HAPset for a SRR (or the first phase of a DRR) tournament is shown in Table 1.

Round	1	2	3
T1	H	A	H
T2	A	H	H
T3	H	A	A
T4	A	H	A

Table 1: HAPset of a SRR tournament with four teams (Swaenepoel, 2023).

Closely associated with HAPs is the concept of breaks: instances where teams play consecutive home matches or consecutive away matches. From the example of Table 1, we can observe that both team 2 and team 3 demonstrate breaks in their scheduling pattern: team 2 plays two consecutive home matches while team 3 plays two consecutive away matches. Minimizing breaks represents a fundamental objective in sports scheduling, as league organizers prioritize schedules with either minimal break occurrences or balanced break distribution across all participating teams to ensure competitive equity (Ribeiro, 2012). Mathematical analysis has established that for a Single Round Robin tournament with n teams (where n is

even), at least $n-2$ breaks must occur, representing an inherent constraint of the problem structure (de Werra, 1981).

2.2.2 The Canonical Method

The canonical method (or circle method) provides an efficient approach for constructing Round Robin tournaments with minimal breaks. This geometric representation involves placing one team at the center of a circle with remaining teams positioned around the circumference. Initially, the central team plays against a designated perimeter team while other teams are paired with opponents positioned diametrically opposite. Subsequent rounds are generated through rotational operations that shift these pairings (Lambrechts et al., 2018).

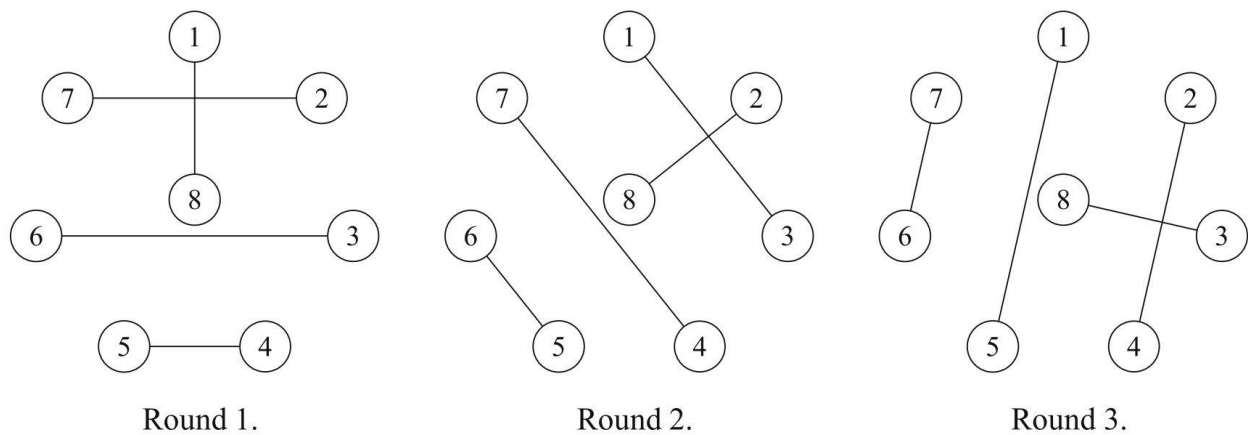


Figure 2: A visual representation of the circle method for 8 teams (Lambrechts et al., 2018).

Despite its computational efficiency, this approach generates problematic carry-over effects: where team C gains competitive advantage by facing team B immediately after B has competed against a strong team A, potentially encountering a weakened opponent due to physical exhaustion or tactical disruptions. Research demonstrates that despite its mathematical elegance, the canonical schedule paradoxically produces maximally unbalanced carry-over distributions (Lambrechts et al., 2018), presenting a notable contradiction given the method's widespread implementation across competitive domains (Goossens & Spieksma, 2012a). However, based on the research by Goossens and Spieksma (2012b), a study of Belgium's Jupiler Pro League spanning over 30 seasons and 10,000 matches found no statistically significant evidence that carry-over effects influence football match outcomes.

2.2.3 Constraint Classification and Solution Methodologies

Tournament scheduling typically involves both hard constraints (absolutely necessary for feasibility) and soft constraints (desirable but potentially violable). Hard constraints include fundamental requirements such as preventing teams from playing multiple matches simultaneously and ensuring venue capacity

limitations are respected. These constraints cannot be violated. Soft constraints represent preferences like minimizing breaks or travel distances, often incorporated into objective functions with weighted penalties for violations (Van Bulck et al., 2020).

Due to the inherent complexity of sports scheduling problems, decomposition approaches have proven particularly effective. The “first-break-then-schedule” methodology pioneered by (Nemhauser & Trick, 1998) divides the problem into sequential stages: initially determining feasible HAPs (often minimizing break occurrences), then constructing a compatible opponent timetable, and finally assigning specific teams to these patterns. Conversely, the “first-schedule-then-break” approach begins by establishing the opponent timetable before determining optimal home-away assignments (Drexel & Knust, 2007). These decomposition strategies have demonstrated particular utility in addressing the multidimensional constraints characteristic of real-world scheduling problems.

Mixed-integer programming (MIP) models represent a common formulation approach for sports scheduling problems. These models comprise decision variables (typically binary indicators for match assignments), objective functions (mathematical expressions quantifying solution quality), and constraint equations (representing both hard and soft constraints). While exact mathematical methods can guarantee optimality for smaller instances, their computational requirements increase exponentially with problem size, limiting practical application for large-scale tournaments (Wright, 2018).

Alternative solution methodologies include metaheuristic algorithms that employ various perturbation techniques to explore the solution space. Simulated Annealing (SA) utilizes controlled acceptance of suboptimal moves to escape local optima, with Wright (2018) successfully applying this approach to cricket league scheduling. Tabu search represents another significant metaheuristic approach that implements memory structures to prohibit revisiting recently explored solutions, strategically restricting the search space to prevent cycling and encourage diverse exploration. Both methods rely on structured perturbation techniques: systematic modifications to solution elements that enable exploration beyond immediate neighborhoods (Kendall et al., 2010). The PEAST algorithm further demonstrates the value of perturbation strategies through its “shuffling operators” that systematically modify current solutions to facilitate exploration of promising alternative regions in the search space (Nurmi et al., 2015).

In practice, sports scheduling often employs hybrid methodologies that combine multiple techniques to address specific contextual requirements. The increasing availability of computational resources continues to expand the range of applicable methodologies, enabling more sophisticated approaches to creating efficient, fair and balanced competition schedules (Ariyaratne & Silva, 2022).

2.3 Time-Relaxed Round Robin Tournament

2.3.1 Structural Characteristics and Advantages

Time-relaxed Round Robin tournaments represent a distinct scheduling paradigm characterized by temporal flexibility, where the number of available time slots exceeds the minimum required for scheduling all fixtures (Van Bulck et al., 2020). This format permits the inclusion of byes, designated periods where specific teams do not compete, creating structural flexibility that accommodates various organizational and logistical constraints.

The expanded temporal framework offers significant advantages for addressing complex operational constraints, particularly regarding team and venue availability (Li, 2024). In non-professional competitive environments (like the competitions Badminton Vlaanderen schedules), this flexibility facilitates accommodation of participant commitments external to the competition, such as professional or familial obligations. Additionally, the format enables effective coordination of limited venue resources across multiple event categories, reducing scheduling conflicts while maintaining competitive structure (Van Bulck & Goossens, 2021).

2.3.2 Competitive Equity Challenges

This increased scheduling flexibility introduces substantial challenges regarding competitive equity considerations. Temporal distribution disparities may result in significant variations in matches played by different teams at specific time points, potentially distorting league standings and undermining competitive balance perceptions (Yi, 2021). Additional equity considerations include differential recovery periods between consecutive fixtures and potential imbalances in consecutive venue assignments (breaks), both requiring systematic management to maintain competitive fairness (Li, 2024; Van Bulck & Goossens, 2021).

2.3.3 Methodological Approaches and Optimization Objectives

Methodological approaches to time-relaxed tournament scheduling have employed various computational strategies. Integer programming formulations enable explicit representation of availability constraints and fairness objectives, though computational complexity increases substantially with problem size. Consequently, decomposition heuristics have emerged as effective approaches for addressing larger problem instances. Relax-and-fix (R&F) and fix-and-optimize (F&O) heuristics represent prominent methodological frameworks that partition decision variables according to either team-based or temporal criteria, sequentially optimizing subproblems to generate high-quality solutions with reduced computational requirements (Van Bulck & Goossens, 2021).

The optimization objectives in time-relaxed contexts extend beyond feasibility considerations to include various fairness dimensions: balanced distribution of team fixtures across the competitive period, minimization of consecutive venue assignments, and equalization of recovery periods between opponents (Yi, 2021). These fairness criteria become particularly important in time-relaxed formats because teams do not necessarily play at the same frequency or during the same time periods (Swaenepoel, 2023).

While compact tournaments have historically dominated sports scheduling literature, increasing recognition of availability constraints in amateur and youth competitions has directed scholarly attention toward time-relaxed scheduling methodologies (Li, 2024; Van Bulck & Goossens, 2021). This shift reflects growing acknowledgment of the operational realities facing non-professional competitive structures and the necessity for scheduling frameworks that effectively balance flexibility and fairness within these contexts.

2.4 Multi-League Scheduling

Multi-league scheduling represents a critical extension of traditional sports scheduling problems, characterized by significant interdependencies and complex resource allocation challenges. While early research concentrated on single, compact Round Robin tournaments, contemporary scheduling demands increasingly reflect the prevalence of amateur and youth competition structures with shared infrastructural constraints (Li, 2024). This shift necessitates scheduling methodologies capable of coordinating multiple leagues simultaneously while accommodating their distinctive operational requirements.

2.4.1 Resource Constraints and Interdependencies

The primary complexity in multi-league scheduling emerges from venue capacity constraints. Amateur and youth sports organizations frequently operate multiple teams across different leagues, with all teams sharing limited facilities (Li, 2024). This resource limitation introduces a fundamental scheduling challenge: preventing concurrent home game assignments that would exceed venue capacity. Similarly, clubs with multiple teams must consider player substitution opportunities between teams in different leagues, requiring temporal coordination of match schedules to facilitate these movements (Schönberger, 2015). This constraint is clearly demonstrated in badminton interclub competitions, where players commonly participate in both men's/women's teams and mixed teams simultaneously. Multi-league scheduling frameworks must therefore implement temporal separation requirements to prevent concurrent match scheduling for different teams containing the same player, ensuring participant availability across all league formats.

Beyond resource constraints, multi-league scheduling must accommodate structural heterogeneity across leagues. Variations in team numbers necessitate different round requirements and potentially distinct scheduling formats (Li et al., 2023).

2.4.2 Mathematical Programming and Heuristic Approaches

Mathematical programming approaches, particularly integer programming (IP) formulations, have demonstrated significant utility in addressing these challenges. These models define decision variables for game assignments and team patterns, with constraints reflecting fundamental requirements like complete fixture lists and venue capacity limitations (Li, 2024).

Given the exponential computational complexity of large-scale multi-league problems, researchers have developed specialized heuristic and metaheuristic approaches to generate high-quality solutions within practical timeframes. Li's dissertation (2024) describes tailored heuristics incorporating local search and perturbation components specifically designed for multi-league contexts. Additionally, the research explores relax-and-fix heuristic methodologies for multi-league scheduling utilizing Incomplete Round Robin tournament structures (Li, 2024).

Memetic algorithms offer another valuable methodological approach to multi-league scheduling problems. Schönberger et al. (2004) addressed the scheduling requirements of a German regional table tennis federation managing more than thirty leagues simultaneously. Their research implemented a hybrid optimization strategy that combined genetic algorithms with specialized local search techniques. This approach utilized constraint propagation methods to systematically improve candidate solutions, while adaptively refining the sequence in which scheduling decisions were made through an evolutionary learning process. By integrating broad search capabilities with targeted solution refinement, this methodology effectively balanced exploration of diverse scheduling possibilities with focused improvement of promising solutions, demonstrating particular effectiveness for complex multi-league environments (Schönberger et al., 2004).

2.4.3 Implementation in Regional Badminton Competitions

Swaenepoel's (2023) implementation for the West-Vlaamse Badminton Federatie demonstrates the practical application of integer programming in multi-league scheduling. This case study addresses scheduling for 18 leagues comprising 114 teams across 23 clubs within a time-relaxed Double Round Robin format. The research employs lexicographic multi-objective optimization through CPLEX technology to address competing scheduling priorities.

The lexicographic approach reflects the hierarchical nature of the scheduling objectives. This methodological framework sequentially optimizes multiple objective functions according to their relative importance, ensuring that improvements in lower-priority objectives never compromise the optimal value of higher-priority objectives. Specifically, Swaenepoel (2023) first minimizes the primary objective function (f_1), which addresses games scheduled on tournament dates, before optimizing the secondary objective (f_2), which focuses on home-away balance distribution.

The implementation addresses multiple constraint categories, including “forbidden weeks”, which are specific time periods when certain team types (mixed or non-mixed teams) cannot participate in competitions due to organizational restrictions or concurrent events. The manual scheduling process frequently violated these constraints, resulting in 19 infeasible fixture assignments. The integer programming formulation successfully eliminated all forbidden week violations while simultaneously reducing tournament date conflicts from 62 to an optimal 18. Advanced formulations incorporating “k-balancedness” constraints further enhanced the schedule quality by limiting cumulative home-away disparities throughout the season. The tournament is considered k-balanced if at any point during the season, the number of home and away games played by each team differs by at most k (Nurmi et al., 2010).

Despite solution times of approximately five hours for advanced models, this represents a substantial efficiency improvement compared to manual processes. This implementation exemplifies how mathematical programming approaches can deliver operational improvements in practical competition environments while effectively balancing multiple competing objectives and maintaining schedule feasibility.

2.4.4 Additional Applications and Contemporary Research Directions

Other real-world applications demonstrate the practical significance of these methodological advancements. The Royal Belgian Football Association collaborated with researchers to address large-scale multi-league scheduling challenges involving hundreds of amateur and youth leagues with varying sizes. Through mixed integer programming models and specialized heuristics, they achieved significant reductions in venue capacity violations while optimizing home-away patterns and league commencement sequencing (Li, 2024).

Contemporary research trends indicate increasing interest in time-relaxed scheduling approaches within multi-league contexts, leveraging expanded time horizons to accommodate complex constraint structures (Li, 2024). Additionally, researchers are exploring integrated methodologies that simultaneously optimize

team grouping and scheduling decisions to address both travel distance minimization and capacity violation prevention (Li, 2024).

Recent developments in multi-league scheduling research demonstrate a clear transition toward methodologies that balance advanced mathematical approaches with real-world application needs. As amateur and youth sports develop more complex organizational structures, these scheduling frameworks offer vital practical support for competition administrators managing the challenging resource allocation problems that define multi-league environments (Swaenepoel, 2023).

2.5 The Sport Teams Grouping Problem

Prior to scheduling matches within a league, teams must first be assigned to groups. The Sport Teams Grouping Problem (STGP), introduced by Toffolo et al. (2019), formalizes this assignment process as a combinatorial optimization problem. Given a set of teams with known locations and strength levels, the objective is to partition the teams into groups that will each compete in a Round Robin tournament, minimizing the total travel distance across all groups while respecting a set of constraints. Each group must contain between a minimum and maximum number of teams, teams within the same group may not be situated further apart than a predefined distance threshold, the difference in strength level between any two teams in the same group may not exceed one, and at most a fixed number of teams from the same club may appear in the same group.

2.5.1 Integer Programming Formulations

Toffolo et al. (2019) present three integer programming formulations of the STGP. The first two are compact formulations. The first (F1) introduces binary variables indicating whether a team is assigned to a given league, whether two teams share a league, and whether a league is part of the solution. The second compact formulation (F2) eliminates the assignment variables and works exclusively with pairwise co-membership variables, which reduces the variable count at the cost of a cubic number of triangle inequality constraints. Both compact formulations are solved directly by a general-purpose IP solver. The third formulation (F3) defines one binary variable per feasible group, resulting in an exponential number of variables. Since all feasibility requirements are embedded in the definition of feasible groups rather than expressed as explicit constraints, F3 provides a strictly stronger linear relaxation than either compact formulation. However, F3 cannot be solved directly and requires a column generation procedure in which new groups are generated iteratively based on dual variable information. Solving F3 therefore requires a branch-and-price algorithm rather than a standard branch-and-bound approach.

2.5.2 Metaheuristic Approach and Computational Results

In addition to the exact methods, Toffolo et al. (2019) develop a simulated annealing heuristic capable of producing high-quality solutions for large instances within practical runtimes. An initial solution is constructed through a randomized best-insertion procedure. Subsequently, simulated annealing iteratively improves this solution by generating neighboring solutions via a ruin-and-recreate procedure, in which a random subset of groups is partially dismantled and rebuilt. Each candidate neighbor is accepted or rejected according to the standard simulated annealing criterion, allowing the algorithm to escape local optima by occasionally accepting worse solutions with a temperature-dependent probability. Computational experiments on real-world instances from the Royal Belgian Football Association demonstrate that the branch-and-price algorithm consistently provides the strongest lower bounds, while simulated annealing reliably produces high-quality feasible solutions. Across all tested instances, the gap between the best lower bound obtained by branch-and-price and the best feasible solution produced by either branch-and-price or simulated annealing does not exceed 1.7%.

For the Badminton Vlaanderen grouping problem, the individual instances per division are sufficiently small that a compact formulation solved with CPLEX is expected to produce optimal solutions without requiring the additional complexity of branch-and-price. The strength constraint used in the STGP is furthermore not applicable in the Badminton Vlaanderen context, as competitive level is already determined by division membership.

2.6 The Incomplete Round Robin Tournament

2.6.1 Conceptual Framework and Methodological Advantages

The Incomplete Round Robin (IRR) tournament presents an alternative approach to traditional complete Round Robin formats by modifying a fundamental structural requirement: rather than mandating that every team competes against all other participants (the “all-play-all” requirement), this format requires only that each team plays an equal number of matches against selectively determined opponents (Li et al., 2025). This methodological adaptation maintains competitive balance through fixture quantity equivalence. The resulting scheduling flexibility proves particularly valuable when addressing large-scale non-professional competitions where comprehensive Round Robin structures become operationally prohibitive due to quadratic growth in required fixtures as participant numbers increase (Li et al., 2025).

Unlike traditional approaches that segment participants into multiple independent leagues, each implementing its own complete Round Robin structure, the incomplete format maintains a unified competition framework while selectively determining opponent pairings (Li et al., 2025). This

methodology shares conceptual similarities with Swiss-system tournaments through its non-eliminating structure and partial opponent coverage. However, a critical distinction exists: while Swiss systems dynamically determine pairings based on progressive tournament results, the Incomplete Round Robin format establishes all fixtures prior to competition commencement, representing a static implementation of selective opponent assignment (Li et al., 2025).

The primary methodological advantages of Incomplete Round Robin tournaments derive from their enhanced flexibility in opponent selection. By strategically biasing opponent selection toward geographically proximate teams, the format facilitates substantial reductions in aggregate travel requirements compared to traditional league structures (Li et al., 2025). Figure 3 provides visual confirmation of this advantage. It presents a simple example with eight teams where the Incomplete Round Robin approach, by more freely picking opponents, achieves lower total travel distance compared to the classic multi-league Round Robin approach. The length of the edges in the figure symbolizes travel distance, clearly showing shorter overall connections in the incomplete format (Li et al., 2025).



Figure 3: A simple example with eight teams (nodes) where each team plays three games, indicated by the edges, according to the all-play-all Round Robin (left) and Incomplete Round Robin (right) approach (Li et al., 2025).

This flexibility extends to venue resource optimization by enabling more efficient distribution of home fixtures across available time slots (Li et al., 2025). Through strategic opponent assignment, the format can significantly reduce simultaneous home fixture scheduling, thereby minimizing venue capacity violations that frequently challenge multi-league competition structures. This capability proves especially valuable in amateur and youth competitions characterized by substantial team volumes sharing limited infrastructural resources (Li et al., 2025).

2.6.2 Operational Benefits and Scaling Properties

Beyond its structural flexibility, the Incomplete Round Robin format provides significant practical advantages for managing large-scale competitions through its more efficient scaling properties. In standard complete Round Robin tournaments, adding teams creates a disproportionate increase in required matches. The incomplete format addresses this challenge by establishing a fixed number of matches per team regardless of total participant count. This approach allows competition administrators to predetermine an appropriate fixture load for each team (e.g., 10 matches per season) that remains constant even as the overall competition grows. This is a particularly valuable feature for extensive youth competitions where traditional formats would require prohibitively high match counts as participation increases (Li et al., 2025).

These theoretical properties are empirically confirmed by Devriesere and Goossens (2025), who applied the IRR to Belgian youth field hockey competitions. Under the traditional multi-league structure, the Royal Belgian Hockey Association (RBHA) partitioned teams into groups of five to six and scheduled each group as a Double Round Robin. Because teams from the same club share infrastructure across multiple categories, the leagues could not be scheduled independently, and the complexity of constructing an integrated schedule manually forced the RBHA to accept suboptimal solutions in which some teams competed on weekdays and against opponents from different strength levels.

By replacing this structure with an IRR, Devriesere and Goossens (2025) demonstrate a reduction in total travel time of 25.9%, with more than 86% of clubs better off under the new design, while simultaneously eliminating all venue capacity violations that were present in the official schedule.

2.6.3 Methodological Challenges

Despite these operational advantages, the Incomplete Round Robin format introduces methodological challenges that must be addressed systematically. Primary among these is the question of ranking integrity. Since teams encounter different sets of opponents, direct win-record comparisons may not accurately reflect relative competitive strength (Li et al., 2025). Without careful design, opponent selection procedures may generate perceived inequities if certain teams consistently face stronger or weaker opposition than other participants.

Fronček (2013) formalizes this concern through a classification of structured incomplete tournaments. In a fair incomplete tournament (FIT), each team plays the same number of games and the total strength of a team's opponents increases proportionally with its own ranking, thereby mimicking the natural balance of a complete Round Robin, in which stronger teams face a collectively weaker set of opponents because they cannot compete against themselves. The complement of a FIT is an equalized incomplete tournament

(EIT), in which every team faces opponents whose combined strength is identical across all participants. A more demanding variant is the handicap incomplete tournament (HIT), in which the strongest team is deliberately assigned the strongest opponents and the weakest team the weakest. Rather than equalizing the raw difficulty of opponent sets, a HIT calibrates competitive difficulty relative to each team's own level, such that all participants face a comparably challenging schedule and retain a comparable chance of winning. Fronček (2013) establishes the existence conditions for such tournaments using distance antimagic graph labelings and magic rectangle sets. While these formal guarantees are most relevant in competitive settings where rankings are published, they offer a useful theoretical reference for IRR applications in which opponent strength balance is an explicit design objective.

A complementary approach to preserving ranking integrity lies in the ranking methodology itself, rather than in the tournament structure. The Generalized Row Sum Method represents a parametric family of scoring rules that systematically adjusts team performance metrics by incorporating the strength of opponents, opponents of opponents, and subsequent network effects through a recursive calculation structure. The method employs a parameter (ε) that quantifies the degree of opponent strength adjustment, with the ranking converging toward simple point-based systems as ε approaches zero (Csató, 2021). Where structural fairness guarantees such as those of Fronček (2013) cannot be fully realized in practice, such adjusted ranking methods offer a post-hoc correction for the asymmetry inherent in incomplete schedules.

Beyond ranking fairness, the IRR format presents combinatorial challenges in optimal opponent assignment. The size of the feasible opponent-selection space grows rapidly with the number of teams and constraints involved (Li et al., 2025), and minimizing travel distances and venue capacity conflicts while maintaining scheduling fairness could therefore require sophisticated algorithmic approaches. Section 2.6.4 discusses the solution approaches that have been proposed to address this computational complexity.

2.6.4 Solution Approaches and Empirical Evidence

Devriesere and Goossens (2025), in their work on scheduling Belgian youth field hockey competitions under an IRR format, formulate the problem as a monolithic integer program that simultaneously determines which teams meet, in which timeslot, and at which venue, subject to constraints on venue capacity, home-away balance, forbidden timeslots, and consecutive match limits. Solved directly with CPLEX, this formulation proved intractable, with an optimality gap exceeding 50% after 24 hours of computation.

The authors therefore develop a matheuristic based on Adaptive Large Neighborhood Search (ALNS). The algorithm starts from an initial feasible solution constructed by decomposing the problem into pairs of consecutive timeslots, and subsequently improves it through iterative destroy-and-repair operations. Neighborhood selection adapts over time based on historical performance, concentrating search effort on the most productive regions of the solution space. Applied to the RBHA youth leagues, the algorithm converged after 12 hours of computation with a gap of less than 1.5% from the linear programming relaxation.

Beyond aggregate travel minimization, Devriesere and Goossens (2025) additionally introduce an equity model that minimizes the maximum deviation between a team's realized travel time and an ideal reference value. By gradually relaxing the bound on total travel time, the algorithm traces a Pareto frontier between aggregate efficiency and individual equity, ultimately yielding a solution in which total travel time remains more than 20 percent below the official schedule while limiting the excess travel imposed on the worst-off individual team.

3. Interclub Competition Scheduling Problem

3.1 Problem Description

Badminton Vlaanderen is responsible for scheduling all interclub competition matches across three leagues: the Liga Competition (the highest competitive level, featuring teams from across Flanders), and the Provincial Competitions of Flemish Brabant (VVBBC) and Limburg. Each league is subdivided into multiple divisions representing distinct competitive levels, and each division comprises one or more groups in which teams compete exclusively against other teams within their group. Matches are scheduled according to a Double Round Robin format (DRR), with one exception: the third division of the Provincial Men's Competition in Limburg operates as a Triple Round Robin (TRR) tournament due to its reduced group size of four teams. Furthermore, the Liga Competition and the Provincial Competitions are not isolated with respect to venue capacity: when a club fields teams in multiple leagues, home matches from different leagues may require the same courts at the same venue, creating capacity conflicts that must be resolved jointly across all competitions.

The interclub competition is further categorized into three competition types: Women's Competition, Men's Competition, and Mixed Competition. The three competition types are not independent: individual players may participate in both the Men's or Women's Competition and the Mixed Competition simultaneously. Within a single competition type however, each player may serve as a registered base player for at most one team (Badminton Vlaanderen, 2025), precluding the need to model scheduling conflicts of this nature. In total, after filtering for the three leagues managed by Badminton Vlaanderen, 317 teams distributed across 48 groups are retained for scheduling. The complete structural overview of all three types is provided in Tables 2, 3, and 4.

Women's Competition				
	Liga			
First Division	Group A: 8 teams			
Second Division	Group A: 6 teams		Group B: 6 teams	
Third Division	Group A: 6 teams	Group B: 6 teams	Group C: 6 teams	Group D: 6 teams
	Provincial Competition in Flemish Brabant (VVBBC)			
First Division	Group A: 8 teams			
Second Division	Group A: 7 teams			

Table 2: Current structure of Women's Competition (there are not enough teams for Provincial Competition in Limburg)

Men's Competition					
	Liga				
First Division	Group A: 7 teams				
Second Division	Group A: 7 teams			Group B: 7 teams	
Third Division	Group A: 7 teams	Group B: 7 teams	Group C: 7 teams	Group D: 7 teams	Group E: 8 teams
	Provincial Competition in Flemish Brabant (VVBBC)				
First Division	Group A: 8 teams				
Second Division	Group A: 6 teams			Group B: 6 teams	
Third Division	Group A: 7 teams		Group B: 7 teams		Group C: 6 teams
Fourth Division	Group A: 7 teams		Group B: 6 teams		Group C: 6 teams
Fifth Division	Group A: 7 teams		Group B: 7 teams		Group C: 6 teams
	Provincial Competition in Limburg				
First Division	Group A: 6 teams				
Second Division	Group A: 5 teams				
Third Division	Group A: 4 teams (Triple Round Robin Tournament)				

Table 3: Current structure of Men's Competition

Mixed Competition				
	Liga			
First Division	Group A: 7 teams			
Second Division	Group A: 7 teams		Group B: 7 teams	
Third Division	Group A: 7 teams	Group B: 6 teams	Group C: 6 teams	Group D: 7 teams
	Provincial Competition in Flemish Brabant (VVBBC)			
First Division	Group A: 7 teams			
Second Division	Group A: 8 teams			
Third Division	Group A: 6 teams			
Fourth Division	Group A: 7 teams		Group B: 7 teams	
Fifth Division	Group A: 5 teams		Group B: 5 teams	
	Provincial Competition in Limburg			
First Division	Group A: 8 teams			
Second Division	Group A: 7 teams			

Table 4: Current structure of Mixed Competition

The competition season spans from September through April. Scheduling is conducted in a time-relaxed setting, meaning that matches are not required to be played every week and the number of matches completed may differ between teams at intermediate points during the season.

The overall planning process is decomposed into two sequential phases. In the first phase, teams within each division are assigned to groups through an optimization model that minimizes total travel distance. Divisions containing only a single group require no assignment decision and are excluded from this phase. The resulting group assignments constitute fixed input for the second phase, in which match schedules are constructed for all groups simultaneously. The current practice for forming groups, described in Section 3.1.4, differs by competition level and provides the starting point against which the optimized assignments are evaluated.

This thesis proposes a model-based replacement for the first phase that optimizes group composition with respect to travel distance. A further motivation for this optimization is comparability: by constructing group assignments that minimize travel distance under the current multi-league structure, a fair baseline is established against which the Incomplete Round Robin (IRR) format can be evaluated. Under this alternative IRR format, the internal group partition within multi-group divisions is removed, as introduced in Section 1.2.

Of the 26 divisions listed in Tables 2, 3, and 4, twelve operate with multiple groups and are therefore subject to the IRR extension. The remaining 14 divisions, each comprising a single group, continue to operate under their existing format (DRR or, in one case, TRR). The optimized DRR grouping produced by the model described in Section 4.1 serves as the baseline against which the IRR format is evaluated, ensuring that any observed difference in travel distance reflects the effect of the format change rather than differences in grouping quality.

Table 5 summarizes the twelve IRR-eligible divisions together with the per-team encounter count that defines the IRR formulation. Each team in an IRR group g plays exactly δ_g^H home encounters and δ_g^A away encounters, where $\delta_g^H = \delta_g^A$. The value of δ_g^H is chosen to approximate the average per-team match volume of the corresponding DRR groups, enabling a direct comparison of travel distance between the two formats. Specifically, δ_g^H is computed as $\text{round}\left(\frac{|T_d|}{K_d}\right) - 1$, where $|T_d|$ denotes the total number of teams in division d , K_d denotes the number of groups in that division, and the rounding follows a round-half-up convention. This per-division calibration ensures that all teams within the same IRR division play an equal number of encounters, as required by the division-wide ranking structure, while ensuring that the majority of teams play exactly the same number of encounters as their DRR counterparts, with the

remainder differing by exactly two encounters: one additional home and one additional away match, or one fewer of each.

For divisions where $\text{round}\left(\frac{|T_d|}{K_d}\right)$ falls below six, δ_g^H is set to a lower bound of five. This bound corresponds to the number of home (or away) encounters a team plays in a DRR group of six, which is the preferred minimum group size prescribed by Article 25§1 of the official competition regulations (Badminton Vlaanderen, 2025). In practice, this lower bound applies to a single division: the fifth division of the VVBBC Mixed Competition, which comprises two groups of five teams.

IRR match count formula:
$$\delta_g^H = \delta_g^A = \begin{cases} \text{round}\left(\frac{|T_d|}{K_d}\right) - 1 & \text{if } \text{round}\left(\frac{|T_d|}{K_d}\right) \geq 6 \\ 5 & \text{if } \text{round}\left(\frac{|T_d|}{K_d}\right) < 6 \end{cases}$$

Division	$ T_d $	K_d	$\frac{ T_d }{K_d}$	$\delta_g^H = \delta_g^A$	DRR matches	IRR matches	Δ
Women's Liga 2nd	12	2	6.00	5	60	60	0
Women's Liga 3rd	24	4	6.00	5	120	120	0
Men's Liga 2nd	14	2	7.00	6	84	84	0
Men's Liga 3rd	36	5	7.20	6	224	216	-8
Men's VVBBC 2nd	12	2	6.00	5	60	60	0
Men's VVBBC 3rd	20	3	6.67	6	114	120	+6
Men's VVBBC 4th	19	3	6.33	5	102	95	-7
Men's VVBBC 5th	20	3	6.67	6	114	120	+6
Mixed Liga 2nd	14	2	7.00	6	84	84	0
Mixed Liga 3rd	26	4	6.50	6	144	156	+12
Mixed VVBBC 4th	14	2	7.00	6	84	84	0
Mixed VVBBC 5th	10	2	5.00	5	40	50	+10
Total					1,230	1,249	+19

Table 5: Divisions converted to the Incomplete Round Robin format under the IRR extension

Across all twelve divisions, the IRR format yields a total of 1,249 matches compared to 1,230 under the DRR baseline, a net increase of 19 matches (+1.54%). This small increase means that any reduction in travel distance under IRR is achieved despite a slightly larger fixture volume, which strengthens rather than weakens the comparative argument for the IRR format.

3.1.1 Grouping Requirements

The construction of valid group assignments is governed by a set of requirements derived from the official competition regulations C320 (Badminton Vlaanderen, 2025) and internal planning guidelines provided by Badminton Vlaanderen (Casier, 2025).

Group size: Each group must contain between six and eight teams (Article 25§1). In exceptional circumstances, a group may contain fewer than six or more than eight teams (Article 25§3).

Equal distribution: The number of teams is distributed as evenly as possible across the groups within a division (Article 25§4).

Club separation: When a club has multiple teams within the same division, those teams are assigned to different groups as a first priority (Article 25§7). When the number of teams a club enters in a division exceeds the number of available groups, strict separation is infeasible. In such cases, the club constraint is relaxed to the minimum value that preserves overall feasibility.

Even when strict separation is achieved, the constraint necessarily places at least one team from a multi-entry club in a group whose members are geographically more distant. This structural penalty is quantified in Section 5.1 and is one of the motivations for exploring the IRR format, which eliminates fixed group boundaries and therefore removes the need for a grouping-level separation constraint.

The grouping requirements described above apply exclusively to multi-group divisions operating under the Double Round Robin format.

3.1.2 Scheduling Requirements

The construction of a valid schedule is subject to a set of requirements that must be strictly respected. The scheduling requirements described below are derived from two primary sources: the official competition regulations C320 (Badminton Vlaanderen, 2025) and internal planning guidelines provided by Badminton Vlaanderen (Casier, 2025).

The following requirements apply to all groups regardless of the tournament format.

Season structure: Each encounter must be assigned to a valid timeslot within the competition season (September–April). The season is divided into two halves: the first round (September–December) and the return round (January–April).

Venue capacity: Each venue offers a finite number of courts per timeslot. Given that an interclub match requires two courts, the number of matches that can be hosted simultaneously at a given venue is bounded by half the number of available courts.

Competition type alternation: Since individual players may participate in both the Men's/Women's Competition and the Mixed Competition, an alternating week structure is imposed to prevent scheduling conflicts. In seasons starting in an odd-numbered year, Mixed Competition encounters are assigned to odd-numbered ISO 8601 weeks and Men's/Women's encounters to even-numbered weeks. This alternation is reversed in even-numbered starting years.

Public holidays and reserved dates: No matches may be scheduled on official Belgian public holidays. Furthermore, certain weekends are entirely blocked across one or more leagues: the Saturday of the Yonex Belgian International tournament, the weekend of the Provincial Adult Championships, the weekend of the Flemish Adult Championships (Liga only), and the weekend of the Belgian Adult Championships (Liga only).

Club tournaments: No matches may be scheduled (home or away) for a team on dates when its club is organizing its own tournament.

Venue unavailability: No home match may be assigned to a date on which the club's sports hall is unavailable.

Preferred scheduling timeslot: Each team specifies a preferred day of the week and a preferred time. Home matches must be scheduled on a timeslot that corresponds to the team's preferred day and preferred time.

Maximum one match per team per week: Each team may be scheduled for at most one encounter per week.

The following requirements apply specifically to groups operating under the Double Round Robin or Triple Round Robin format.

Home and away balance: Under the Double Round Robin format, exactly one encounter between each pair of teams takes place during the first round, and the return encounter is scheduled during the return round. Each team must play exactly once at home and once away against every opponent across the full season. Within each half of the season, the difference between the number of home and away matches played by a team may not exceed one, ensuring that no team is disproportionately burdened with home or away fixtures in either half independently of the overall season balance.

Home and away balance under Triple Round Robin: For the one group operating under a Triple Round Robin format, additional constraints apply. Each pair of teams meets exactly three times across the season, with at most two encounters in either half. No team may host the same opponent more than twice, and

both the overall home/away balance across the full season and the distribution of matches across the two halves are constrained to differ by no more than one.

Intra-club encounters: When multiple teams from the same club are assigned to the same group, they must face each other as the first or second encounter of both the first round and the return round: that is, before either team has played more than one match against any other opponent (per regulation C320, Article 25§8).

The following requirements apply specifically to groups operating under the Incomplete Round Robin format.

Incomplete Round Robin encounter count: Each team in an IRR group must play exactly δ_g^H home encounters and δ_g^A away encounters over the full season, where $\delta_g^H = \delta_g^A$. This requirement guarantees a uniform fixture load across all teams in the group. The total number of encounters per team is therefore $2 \cdot \delta_g^H$. The values of δ_g^H per division are listed in Table 5.

Opponent selection under IRR: Under the IRR format, each team may host a given opponent at most once over the full season, so that any unordered pair of teams meets at most twice in total. Within each half of the season, at most one encounter may take place between any pair. Teams are not required to play against every other team in the group. The scheduling model selects the fixture set jointly with the timeslot assignment.

Intra-club encounters under IRR: Under the IRR format, encounters between teams from the same club are forbidden entirely. This constitutes a strict implementation of Article 25§7, which requires clubs to place their teams in separate groups whenever possible. Because the IRR format eliminates fixed group boundaries, full intra-club separation can be enforced without exception.

3.1.3 Schedule Quality Considerations

Beyond the hard requirements listed above, several additional dimensions influence the quality of a schedule. Which of these dimensions are actively optimized depends on the scheduling format under consideration.

First, scheduling matches on certain undesirable dates (e.g. 30 December) is considered detrimental to schedule quality. In practice, matches assigned to such dates frequently need to be rescheduled, causing organizational overhead and inconvenience for players. Badminton Vlaanderen therefore considers the avoidance of undesirable dates a higher priority than the minimization of triple breaks described next.

Second, a schedule is considered of higher quality when teams are not assigned three or more consecutive home or three or more consecutive away matches, hereafter referred to as a “triple break”. Such

sequences are perceived as disadvantageous from a competitive fairness perspective, though Badminton Vlaanderen regards them as a less critical concern than the other quality dimensions (Casier, 2025).

Third, under the IRR format, travel distance becomes a direct optimization objective in the scheduling phase. In the DRR format, travel distances are addressed during the grouping phase (Section 4.1), and the scheduling model treats group composition as fixed input.

Fourth, as noted in Section 1.2, the IRR format produces a single division-wide ranking in which not all teams face the same opponents, introducing the possibility that some teams face systematically stronger or weaker opposition than others. Since all teams compete within a single ranking, this imbalance directly affects their final standings. The dispersion of opponent strength across teams within an IRR group is therefore considered an additional quality dimension in the evaluation of IRR schedules. The formulation of the constraint addressing this concern is presented in Section 4.3.5.

Accordingly, the scheduling model for the current format targets unwanted date avoidance as its objective and employs constraints to reduce triple breaks (Sections 4.2.1 and 4.2.2), while the IRR extension minimizes total travel distance as its objective and controls opponent strength balance through additional constraints (Section 4.3). In the IRR formulation, unwanted dates are enforced through a hard constraint rather than an objective. The motivation for this modelling choice is discussed in Section 4.3. Triple breaks are not actively minimized in the IRR formulation. The IRR extension is evaluated along two quality dimensions, travel distance and opponent strength dispersion, and triple break reduction is excluded to preserve the clarity of this two-dimensional comparison. The rationale for this scope decision and its implications are discussed in Section 6.2.

3.1.4 Current Scheduling Practice

The operational scheduling process employed by Badminton Vlaanderen follows a sequential timeline spanning approximately four months (Casier, 2025). In the first phase, clubs register their teams, venue availability, preferred playing times, and court capacities. Teams are then assigned to groups by June 15, after which Round Robin schemas are configured in the Competition Planner software provided by toernooi.nl, with scheduling finalized by July 15.

The methodology for forming competition groups differs between competition levels. For the Liga Competition, groups are composed based on geographical proximity assessed by visual inspection. For the Provincial Competitions, teams are distributed across groups by lottery, as the provincial boundary already constrains travel distance to some extent (Casier, 2025). In neither case does Badminton Vlaanderen apply criteria related to the balance of team strength between groups.

Until the 2023-2024 season, all schedules were constructed entirely by hand: a blank fixture list was exported from the Competition Planner and populated group by group in separate Excel worksheets. From the 2024-2025 season onward, a brute-force backtracking script has been used to automate the initial assignment. The script places encounters one at a time and backtracks whenever a constraint violation is detected, iterating until a feasible schedule is found. While this approach significantly reduces manual effort, it provides no guarantee of schedule quality with respect to criteria such as triple breaks or undesirable dates. Furthermore, the output still requires manual verification and correction, as the script does not consistently enforce all scheduling requirements (Casier, 2025). The integer programming approach developed in Section 4.2 addresses both limitations by formulating all requirements as hard constraints and optimizing schedule quality through an explicit objective function.

3.2 Data

3.2.1 Raw Data Sources

The scheduling problem is instantiated from three primary data sources provided by Badminton Vlaanderen, complemented by a configuration file that governs season-level parameters.

The core input is a JSON file provided by Badminton Vlaanderen, structured as an array of 132 club objects. Each club object contains three top-level fields: *name*, *locations*, and *teams*. The *locations* field is an array of venue objects, each identified by a unique *id* and described by its *name* and address information. Each venue carries an *availabilities* array that encodes the home scheduling availability of the club. Every availability entry consists of two components: a *days* array specifying the recurring weekly pattern, where each element lists a weekday, a start time, an end time, and the number of available courts, and an *exceptions* array capturing date-specific overrides, where a court count of zero indicates a full closure and any positive value indicates a reduced or modified capacity. The *teams* field of each club is an array of team objects, each carrying a unique *id*, a display *name*, a *teamNumber*, a competition *type* (Men's, Women's, or Mixed), and nested objects for *event* (the league), *subEvent* (the division), and *draw* (the group within that division). Additionally, each team records a *preferredDay* and *preferredTime*, reflecting the club's preferred scheduling slot.

It is important to note that the JSON file encompasses teams from competitions beyond the scope of Badminton Vlaanderen's planning responsibility. Specifically, it also includes teams participating in the Provincial Competitions of East-Flanders, Antwerp, and West-Flanders, which are administered independently. These teams are identified and excluded during data preprocessing by filtering on the *event.name* field, retaining only the three competitions managed by Badminton Vlaanderen: the Liga

Competition, the Provincial Competition of Flemish Brabant, and the Provincial Competition of Limburg. After filtering, 72 of the 132 clubs and 317 of the 823 teams remain relevant for the planning problem.

A properties-based configuration file specifies all season-level parameters governing the scheduling process. The file was provided by Badminton Vlaanderen in a partially completed state and subsequently extended to support additional modelling requirements. The parameters provided by Badminton Vlaanderen include the season boundary dates, specifically the start of the competition (1 September 2025), the midpoint separating the first and return round (1 January 2026), and the end of the competition (30 April 2026), as well as the week alternation rule specifying whether Mixed Competition matches are assigned to odd or even ISO 8601 weeks, set to odd-numbered weeks for the 2025-2026 season, and a list of globally forbidden dates on which no matches may be scheduled, comprising public holidays and weekends reserved for major tournaments on the Badminton Vlaanderen calendar.

The following parameters were added as part of this work to support the full constraint set of the IP model. First, competition-specific restricted dates were introduced under the prefix *restricted-days*, allowing league-level forbidden weekends to be specified independently for each competition. For the 2025-2026 season, the Liga Competition carries additional restricted dates corresponding to the Flemish Adult Championships and the Belgian Adult Championships weekends, while the Provincial Competitions of Flemish Brabant and Limburg have no additional restrictions beyond the global forbidden dates. Second, a set of undesirable dates was defined under the key *unwanted-days*, corresponding to the period between Christmas and New Year (28-30 December 2025 and 2 January 2026), during which scheduling is discouraged but not prohibited. Third, the path to the club tournament file was specified via *club-tournament-days-file*.

An Excel file lists all club-organized tournaments for the 2025-2026 season, specifying for each entry the tournament name, the organizing club, and the corresponding date or dates. These entries are used to populate the set E_c for each club c : on dates when a club organises its own tournament, it may not participate in any match (home or away).

Badminton Vlaanderen additionally provided the official schedules produced for the 2025-2026 season in Excel format, one file per competition type. Each file lists scheduled matches with columns for date, time, competition type, subdivision, group, match number, home team, away team, number of courts, and venue. These reference schedules serve a dual purpose: they are used to validate the correctness of the model's output against the schedules produced by the federation, and they provide a benchmark against which solution quality can be compared.

Two derivative JSON files were constructed from the primary data source for use in the scheduling phase. The first file augments the draw objects with a *roundRobinType* field (DRR or TRR) and assigns teams to the optimal groups determined by the grouping model of Section 4.1. This file serves as input for scheduling under the current DRR format. The second file is used exclusively for the IRR extension: draws belonging to multi-group divisions are labeled as IRR in the *roundRobinType* field, and each team object in these divisions carries a *strength index* published on the Badminton Vlaanderen website. This index is derived from the national rankings of its rostered players. It is used in the opponent strength balance component of the IRR formulation (Section 4.3.5).

3.2.2 Derived Datasets

The solver does not operate directly on the raw input data. Instead, a preprocessing pipeline implemented in Java transforms the raw sources into the structured sets and parameters required by the IP model.

From the full JSON, only teams belonging to the three competitions managed by Badminton Vlaanderen are retained. This yields 317 teams distributed across 48 groups, of which 47 operate under a Double Round Robin format and one under a Triple Round Robin format, as described in Section 3.1.

The weekly availability patterns recorded in the JSON are expanded into a concrete set of dated timeslots S spanning the full competition season. Each timeslot represents a unique combination of venue, date, and time window, and carries a court capacity derived from the baseline weekly pattern. Date-specific exceptions override the baseline capacity where applicable, including full closures. The resulting set contains 8,814 timeslots in total, of which 4,385 are relevant to the planning of Badminton Vlaanderen after filtering for the correct competition scope and week-type alternation rule. The timeslots are subsequently partitioned into the first-round set S_f and the return-round set S_r using the midpoint date of 1 January 2026, and further indexed by ISO week across a total of 35 planning weeks.

Several derived eligibility sets are constructed to restrict the domain of the decision variables prior to passing the model to the solver. For each team i , the home availability set H_i is constructed by intersecting the expanded timeslots of the team's club with the group-specific allowed slots. This intersection is then filtered by successively excluding globally and league-specifically forbidden dates, applying the competition-type week alternation rule, removing dates blocked by club tournaments or venue closures, and retaining only timeslots whose day of week and time window match the team's *preferredDay* and *preferredTime* as specified in the input data. For each group g , the set S_g is constructed as the union of the home availability sets H_i across all teams i belonging to g , collecting all timeslots at which a team in the group is eligible to host a home match. By construction, S_g inherits the week-type and season boundary restrictions already encoded in each H_i , as well as all team-level eligibility conditions including

preferred day and time constraints. Teams are additionally indexed by club through T_c , and timeslots are grouped by ISO week through S_w , enabling the enforcement of the maximum-one-match-per-week constraint. Together, these sets define the feasible region of the model prior to optimization.

The location data embedded in the JSON file additionally serves as input for the grouping phase. For clubs operating multiple venues, the first listed location is used as the club's reference point. Pairwise driving distances $d_{i,j}$ in kilometers between the primary venues of all relevant clubs are computed using the Google Maps Distance Matrix API and stored as a CSV file indexed by club identifier. This distance matrix is used as direct input to the grouping optimization model and is subsequently reused in the Incomplete Round Robin analysis. Since the model assumes a symmetric distance matrix, symmetry is enforced explicitly after all API calls: for each pair of clubs (i, j) , both entries are set to the average of the two directional values returned by the API, rounded to the nearest whole kilometer. This accounts for minor asymmetries in the routing data arising from one-way streets or directional routing differences.

When the IRR format is active for a division, the preprocessing pipeline constructs a single pooled team set T_g containing all teams of that division, in place of the per-group team sets used under the DRR format. No group assignment is computed for these divisions. T_g serves directly as the opponent pool from which the scheduling model selects fixture pairs.

4. Methodology

4.1 Grouping Problem IP Model

The team grouping problem is formulated as an Integer Programming model, solved independently for each division $d \in D$ containing multiple groups. The formulation is based on the compact formulation F1 of Toffolo et al. (2019). In the original Sport Teams Grouping Problem (STGP) formulation, F1 includes a binary variable z_ℓ indicating whether a league is active, since the number of leagues is treated as an upper bound and some may remain unused. In the BV context, the number of groups per division K_d is fixed in advance and every group must receive teams, so $z_g = 1$ for all $g \in G_d$ by construction. The activation variable is therefore omitted. The strength constraint present in the original STGP is likewise omitted, as all teams within a division compete at the same level by definition.

The objective function minimizes the total round-trip driving distance across all divisions. In a Double Round Robin format, each pair of co-grouped teams plays two matches. The objective sums over all ordered pairs (i, j) with $i \neq j$: each term $2 \cdot d_{i,j} \cdot y_{i,j}$ represents the round-trip travel cost incurred by the visiting team j when team i hosts the fixture. The symmetric term $2 \cdot d_{j,i} \cdot y_{j,i}$ captures the return fixture in which j hosts i . Since $d_{i,j} = d_{j,i}$ and $y_{i,j} = y_{j,i}$ at optimality, the total contribution of each co-grouped pair equals $4 \cdot d_{i,j} \cdot y_{i,j}$, consistent with two round-trip journeys over the season. The factor two in the objective converts one-way pairwise distances to round-trip distances for a single fixture. Since this factor is a positive constant applied uniformly to all terms, it does not affect the optimal assignment of decision variables, it only scales the objective value. Results in Section 5.1 are reported directly as round-trip distances.

Sets

D	Set of divisions with multiple groups
$T_d \subseteq T$	Teams in division d
G_d	Set of groups in division d , $ G_d = K_d$
$T_c \subseteq T$	Teams from club c

Parameters

$d_{i,j}$	One-way driving distance (km) between home venues i and j , symmetric ($d_{i,j} = d_{j,i}$). Computed via the Google Maps API as described in Section 3.2.2.
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$m_d^- = \lfloor T_d / K_d \rfloor$	Minimum group size for division d
$m_d^+ = \lceil T_d / K_d \rceil$	Maximum group size for division d
$c_{c,d}^+ = \lceil T_c \cap T_d / K_d \rceil$	Maximum number of teams from club c in division d that can be assigned to the same group

Decision Variables

$x_{i,g} \in 0,1$	1 if team i is assigned to group g , 0 otherwise, $\forall d \in D, i \in T_d, g \in G_d$
$y_{i,j} \in 0,1$	1 if teams i and j are assigned to the same group, $\forall d \in D, i, j \in T_d, i \neq j$

Objective

$$\min \sum_{d \in D} \sum_{\substack{i, j \in T_d \\ i \neq j}} 2 \cdot d_{i,j} \cdot y_{i,j}$$

Constraints

$\sum_{g \in G_d} x_{i,g} = 1$	$\forall d \in D, i \in T_d$	(GRP-1)
$m_d^- \leq \sum_{i \in T_d} x_{i,g} \leq m_d^+$	$\forall d \in D, g \in G_d$	(GRP-2)
$\sum_{i \in T_c \cap T_d} x_{i,g} \leq c_{c,d}^+$	$\forall d \in D, g \in G_d, \forall c \in C$	(GRP-3)
$x_{i,g} + x_{j,g} \leq y_{i,j} + 1$	$\forall d \in D, i, j \in T_d, g \in G_d$	(GRP-4)
$m_d^- - 1 \leq \sum_{\substack{j \in T_d \\ j \neq i}} y_{i,j} \leq m_d^+ - 1$	$\forall d \in D, i \in T_d$	(GRP-5)

Constraint (GRP-1) ensures each team is assigned to exactly one group within its division. Constraint (GRP-2) enforces the group size bounds. The bounds m_d^- and m_d^+ are computed per division as $\lfloor |T_d| / K_d \rfloor$ and

$\lceil |T_d|/K_d \rceil$ respectively, guaranteeing feasibility and enforcing equal size distribution as required by regulation C320, Article 25§4. For most divisions these bounds fall within the interval $[6, 8]$ prescribed by Article 25§1. Where the team count per division does not permit this, the computed bounds take precedence, consistent with the exceptional provision of Article 25§3.

Constraint (GRP-3) limits the number of teams from the same club in any single group. When $|T_c \cap T_d| \leq K_d$, this enforces strict separation ($c_{c,d}^+ = 1$) as required by Article 25§7. When a club fields more teams in a division than there are groups, strict separation is infeasible and $c_{c,d}^+$ is set to $\lceil |T_c \cap T_d|/K_d \rceil$, the minimum value that preserves overall feasibility.

Constraint (GRP-4) links the x and y variables: whenever teams i and j are assigned to the same group, $y_{i,j}$ is forced to 1. The minimization objective drives $y_{i,j}$ to 0 for all pairs not sharing a group, since reducing $y_{i,j}$ can only improve the objective.

Constraint (GRP-5) requires that each team has between $m_d^- - 1$ and $m_d^+ - 1$ co-group members. This constraint strengthens the linear relaxation of the model. Without it, the LP relaxation admits a trivial fractional solution in which all $x_{i,g} = 1/K_d$ for every group $g \in G_d$ and all $y_{i,j} = 0$. Setting $x_{i,g} = 1/K_d$ satisfies Constraint (GRP-1), since the values sum to one across all groups. For Constraint (GRP-4), the left-hand side evaluates to $1/K_d + 1/K_d = 2/K_d$, which does not exceed $y_{i,j} + 1 = 1$ for any $K_d \geq 2$, so Constraint (GRP-4) is satisfied with all $y_{i,j} = 0$. The objective value of this fractional solution is therefore zero regardless of the distances involved, rendering the LP lower bound completely uninformative and preventing the branch-and-bound solver from pruning any part of the search tree. Constraint (GRP-5) eliminates this degenerate solution by enforcing that each team must have a minimum number of co-group members, which forces the y variables to take positive values and produces a meaningful lower bound.

4.2 Scheduling Model for Current Format

4.2.1 Base IP Model

The scheduling problem is formulated as an Integer Programming (IP) model. The model operates on a set of pre-generated timeslots, each representing a unique combination of venue, date, and time at which a home match can be hosted. Every timeslot carries a capacity parameter corresponding to the number of available courts at that venue during that window.

A match between team i (home) and team j (away) is assigned to a timeslot s . The central decision variable $x_{i,j,s}$ is therefore defined over pairs of teams and timeslots, capturing both the assignment of a match and its home/away designation simultaneously. Rather than instantiating the full Cartesian product of teams and timeslots, variables $x_{i,j,s}$ are only created for combinations satisfying two domain conditions: teams i and j must belong to the same group g , and timeslot s must lie within the home availability set H_i of team i . Since H_i already encodes all eligibility conditions, including the preferred day and time of the home team, no explicit constraint is required to enforce this requirement. Infeasible timeslots are excluded from the variable domain prior to model construction, rendering the preferred day and time restriction implicit in the definition of the decision variable rather than expressed as a separate constraint. This pre-filtering substantially reduces the number of decision variables, improving solver efficiency without affecting solution quality.

The three-dimensional timeslot definition departs from the convention in much of the time-relaxed scheduling literature, where a slot typically corresponds to a single date or date-time pair. The departure is motivated by the structure of the input data provided by Badminton Vlaanderen, which is organized at the venue level: clubs may operate multiple venues, and each venue carries its own recurring weekly pattern, court capacity, and date-specific availability exceptions, such as full closures or reduced court counts on particular dates. Since these exceptions and capacities are defined per venue rather than per club, any formulation that aggregates availability across venues prior to model construction would lose this granularity and require additional preprocessing to reconstruct it. A conventional (date, time) formulation would therefore need to either perform such aggregation, at the cost of discarding venue-specific information, or reintroduce the venue dimension explicitly through a four-indexed decision variable and auxiliary linking constraints. The latter is equivalent to the approach adopted here, since a (date, time, venue) triple encodes the same information as the current timeslot index s . The present formulation avoids both alternatives by absorbing the venue dimension directly into the timeslot index, preserving the venue-level structure of the input data, including all exceptions and capacity variations, without auxiliary constraints or preprocessing steps.

Alongside the primary binary variables, two integer auxiliary variables are introduced to track cumulative match progress for the purpose of enforcing intra-club scheduling requirements. The variable $\text{prev}_i^f(s)$, where the superscript f denotes the first round (September–December), counts the number of matches, both home and away, completed by team i strictly before timeslot s within the first round. Its counterpart $\text{prev}_i^r(s)$, where r denotes the return round (January–April), is defined analogously for the second half of the season. The complete sets, parameters, decision variables, objective function, and constraints of the base model are represented below.

Sets

L	Set of leagues
G	Set of groups
$G^{DRR} \subseteq G$	Set of groups with a Double Round Robin tournament
$G^{TRR} \subseteq G$	Set of groups with a Triple Round Robin tournament
T	Set of teams
$T_g \subseteq T$	Set of teams in group g
C	Set of clubs
$T_c \subseteq T$	Set of teams belonging to club c
S	Set of all timeslots (venue-date-time combinations)
$S^f, S^r \subset S$	Timeslots in the first and return round
$S_g \subset S$	Set of timeslots in group g
$S_{g,f}, S_{g,r} \subset S_g$	Timeslots of group g in the first and return round
$H_i \subset S_{g(i)}$	Timeslots in which team i can play at home
$H_{i,f}, H_{i,r} \subseteq H_i$	Timeslots in which team i can play at home in the first and return round
$S_c \subset S$	Set of timeslots of club c
W	Set of all planning weeks in the competition season
$S_w \subset S$	Timeslots in week w

$S_{g,w} = S_g \cap S_w$	Timeslots in group g falling in week w
$S^{unwanted}$	Set of undesirable (but not forbidden) dates
F	Set of public holidays and globally forbidden dates
K_l	Set of forbidden dates specific to league l
E_c	Set of tournament dates of club c

Parameters

ζ_s	Number of available courts at the venue associated with timeslot s
$c(i)$	Club to which team i belongs
$l(i)$	League in which team i competes
$g(i)$	Group in which team i competes

Decision Variables

$x_{i,j,s} \in 0,1$	1 if team i plays at home against team j in timeslot s , 0 otherwise, $\forall g \in G, \forall i, j \in T_g, i \neq j, \forall s \in H_i$
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Auxiliary Variables

$\text{prev}_i^f(s) \in \mathbb{Z}_{\geq 0}$	the number of matches played by team i prior to timeslot s within the first round, $\forall g \in G, \forall i \in T_g, \forall s \in S_{g,f}$
$\text{prev}_i^r(s) \in \mathbb{Z}_{\geq 0}$	the number of matches played by team i prior to timeslot s within the return round, $\forall g \in G, \forall i \in T_g, \forall s \in S_{g,r}$

Objective

$$\min Z = \sum_{i \in T} \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S^{\text{unwanted}} \cap H_i} x_{i,j,s}$$

The objective minimizes the total number of matches assigned to timeslots belonging to S_{unwanted} , a set of dates that are not forbidden but are considered undesirable by the organization. Triple breaks are addressed separately through hard constraints, as described in Section 4.2.2.

Constraints

$$\sum_{s \in H_i} x_{i,j,s} = 1 \quad \forall g \in G^{DRR}, \forall i, j \in T_g, i \neq j \quad (1)$$

$$\sum_{s \in S_{g,f}} (x_{i,j,s} + x_{j,i,s}) = 1 \quad \forall g \in G^{DRR}, \forall i, j \in T_g, i \neq j \quad (2)$$

$$\sum_{s \in S_{g,w}} \sum_{j \neq i} (x_{i,j,s} + x_{j,i,s}) \leq 1 \quad \forall g \in G, \forall i \in T_g, \forall w \in W \quad (3)$$

$$\sum_{i \in T_c} \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} x_{i,j,s} \leq \left\lfloor \frac{\zeta_s}{2} \right\rfloor \quad \forall c \in C, \forall s \in S_c \quad (4)$$

$$x_{i,j,s} + x_{j,i,s} = 0 \quad \forall g \in G, \forall i, j \in T_g, \forall s \in F \cup K_{l(i)} \cup E_{c(i)} \quad (5)$$

$$\text{prev}_i^f(s) = \sum_{\substack{u \in S_{g,f} \\ u < s}} \sum_{j \neq i} (x_{i,j,u} + x_{j,i,u}) \quad \forall g \in G, \forall i \in T_g, \forall s \in S_{g,f} \quad (6)$$

$$\text{prev}_i^f(s) \leq 1 + M(1 - x_{i,j,s} - x_{j,i,s}) \quad \forall g \in G, \forall i, j \in T_g, i \neq j, c(i) = c(j), s \in S_{g,f} \quad (7)$$

$$\text{where } M = \begin{cases} |T_{g(i)}| - 1 & \text{if } g(i) \in G^{DRR} \\ 2(|T_{g(i)}| - 1) & \text{if } g(i) \in G^{TRR} \end{cases}$$

Constraints (6) and (7) hold analogously for the return round, with $S_{g,f}$ and $H_{i,f}$ replaced by $S_{g,r}$ and $H_{i,r}$ respectively.

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{i,f}} x_{i,j,s} - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{j,f}} x_{j,i,s} \leq 1 \quad \forall g \in G^{DRR}, \forall i \in T_g \quad (8)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{j,f}} x_{j,i,s} - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{i,f}} x_{i,j,s} \leq 1 \quad \forall g \in G^{DRR}, \forall i \in T_g \quad (9)$$

Constraint (1) ensures that, under the Double Round Robin format, each ordered pair of distinct teams within a group plays exactly one home match against each other over the full season. Together with the definition of the decision variable $x_{i,j,s}$, this guarantees that every team plays exactly once at home and once away against each opponent. Constraint (2) enforces the season structure: exactly one encounter, in either direction, between each pair of teams must take place during the first round. Since Constraint (1)

already guarantees one encounter per direction per season, Constraint (2) implicitly ensures that the return encounter falls in the second half of the season.

Constraint (3) imposes the maximum-one-match-per-week restriction: across all timeslots in week w belonging to group g , each team may appear in at most one match, whether as home or away side. Constraint (4) enforces venue capacity. Since an interclub match requires two courts, the number of simultaneous home matches hosted by a club at a given timeslot is bounded by $\lfloor \zeta_s/2 \rfloor$, where ζ_s denotes the total number of courts available at that timeslot. Constraint (5) prohibits the scheduling of any match on forbidden dates, comprising Belgian public holidays (F), league-specific blocked weekends ($K_{l(i)}$), and dates on which the club of team i organizes its own tournament ($E_{c(i)}$). The latter applies to both terms: $x_{i,j,s}$ prevents team i from hosting a match on such a date, while $x_{j,i,s}$ prevents team i from being required to play an away match on the same date, ensuring that players of club $c(i)$ remain available to participate in their club's tournament.

Constraints (6) and (7) together enforce the intra-club early-encounter requirement (regulation C320, Article 25§8). Constraint (6) defines $\text{prev}_i^f(s)$ as the total number of matches played by team i before timeslot s within the first round, computed as the sum of all x -variables involving team i at timeslots strictly preceding s . Constraint (7) then applies a big- M formulation: if teams i and j belong to the same club and are scheduled to meet at timeslot s , the number of prior matches played by each team is forced to be at most one, ensuring the encounter takes place as the first or second fixture of the round. When $x_{i,j,s} = x_{j,i,s} = 0$, the big- M term renders the constraint non-binding. The value of M is a valid upper bound on $\text{prev}_i^f(s)$, set to $|T_{g(i)}| - 1$ for DRR groups, since a team plays at most $|T_{g(i)}| - 1$ matches within a single round, and to $2(|T_{g(i)}| - 1)$ for TRR groups, where a team may play up to two encounters against the same opponent within a single round. Both constraints hold analogously for the return round, with $S_{g,f}$ and $H_{i,f}$ replaced by $S_{g,r}$ and $H_{i,r}$ respectively.

Constraints (8) and (9) enforce home/away balance within each half of the season for DRR groups. The difference between the number of home and away matches played by any team in either the first or the return round may not exceed one, preventing disproportionate home or away burdens in either half independently of the season-level balance. These constraints are defined only for the first round. The corresponding return-round balance need not be modelled explicitly, as it is implied by Constraints (1), (2), (8), and (9) jointly. Constraint (1) fixes the total number of home matches and away matches per team over the full season at $n - 1$ each. Constraint (2) fixes the total number of matches per team per half at $n - 1$. Given these two equalities, the home/away imbalance in the return round is necessarily equal in magnitude and opposite in sign to the imbalance in the first round. Bounding the first-round imbalance to at most one therefore automatically bounds the return-round imbalance to at most one.

The base model includes one group operating under a Triple Round Robin (TRR) format: Limburg Men's third division, which comprises four teams. In this format, each pair of teams meets exactly three times across the season rather than twice, which necessitates a separate set of constraints governing encounter counts, home/away balance, and match distribution across the two rounds. Because TRR only applies to a single group of four teams, its full constraint formulation is provided in Appendix A. The scheduling requirements underlying those constraints are stated in Section 3.1.2.

4.2.2 Bucket Constraints for Triple Break Reduction

As described in Section 3.1.3, a schedule is considered of higher quality when teams are not assigned three or more consecutive home or away matches. A natural approach to reducing triple breaks is to detect them explicitly through auxiliary binary variables and penalize them in the objective function, adapting the break-detection formulation of (Knust, 2010) from standard breaks to triple breaks. In a time-relaxed context, however, this approach is computationally prohibitive. Because consecutive matches do not need to occupy consecutive timeslots, every ordered combination of three timeslots at which a team could potentially play must be considered as a candidate triple break. On the actual BV instance, this produces 71,269,343 binary auxiliary variables and 142,538,686 constraints. In practice, the model cannot even be constructed: invoking the variable generation procedure in CPLEX results in an `OutOfMemoryError`.

This section therefore adopts an indirect strategy: rather than enumerating all possible triple break patterns, two families of hard constraints are introduced that enforce distributional balance of home and away matches across temporal windows, thereby reducing the number of triple breaks without introducing additional decision variables into the base model. The use of temporal intervals to control match distribution appears in related work in the time-relaxed scheduling literature. Schönberger et al. (2004) impose minimum and maximum match counts per team within equidistant intervals to spread fixtures evenly across the season. Devriesere and Goossens (2025) take a related approach in their construction heuristic for Belgian youth field hockey, decomposing the problem into pairs of consecutive timeslots and limiting each team to at most one home and one away match per pair, which structurally prevents triple breaks in the initial solution. The bucket and rolling window constraints introduced below generalize these ideas by allowing parametric control over both window size and the permitted number of same-direction matches per window.

The most direct instantiation of this framework for eliminating triple breaks is the rolling window maximum constraint with $q = 3$ and $M = 2$, requiring that within any three consecutive active weeks a team plays at most two matches in the same direction. This configuration is infeasible on the BV instance, which constitutes direct evidence that triple breaks cannot be fully eliminated. The parameter values and

constraint families are therefore not fixed in advance but are identified through empirical screening, the results of which are reported in Section 5.2.

Active weeks and bucket definition

The competition schedule partitions teams into two alternating categories: Men's and Women's teams play exclusively in even ISO weeks, while Mixed teams play exclusively in odd ISO weeks. Combined with the maximum-one-match-per-week Constraint (3), this means that each team plays at most one match every two calendar weeks. As a consequence, a bucket defined over calendar weeks would contain at most half as many scheduling opportunities as its size suggests: a four-calendar-week bucket offers only two weeks in which a given team can actually be assigned a match. Defining bucket boundaries in calendar weeks would therefore not make sense in this context.

Instead, buckets are defined over *active weeks* rather than calendar weeks, where an active week for team i is a planning week in which team i is both eligible to play, given the competition-type alternation rule, and has at least one available timeslot (home or away). For team i , the ordered sequence of active weeks is denoted $\mathcal{W}_i = (w_1^i, w_2^i, \dots)$. Consecutive active weeks in this sequence are typically separated by two calendar weeks due to the alternation rule, though gaps may be larger when forbidden dates, club tournaments, or venue closures eliminate all available timeslots in an otherwise eligible week.

Two families of temporal windows are defined over $\mathcal{W}_i$. Non-overlapping buckets of q consecutive active weeks partition the sequence as:

$$B_k^i = \{w_{(k-1)q+1}^i, \dots, w_{kq}^i\}, \quad k = 1, \dots, \left\lfloor \frac{|\mathcal{W}_i|}{q} \right\rfloor$$

Overlapping rolling windows of width q are defined as:

$$R_k^i = \{w_k^i, w_{k+1}^i, \dots, w_{k+q-1}^i\}, \quad k = 1, \dots, |\mathcal{W}_i| - q + 1$$

The following sets extend those introduced in Section 4.2.1 and are required specifically for the bucket constraint formulation:

Sets

$\mathcal{W}_i$	Ordered sequence of active weeks for team i : planning weeks in which team i has at least one available timeslot, given the even/odd alternation rule and all applicable date-level restrictions
q	Bucket size parameter: number of consecutive active weeks per bucket or rolling window, varied across experimental configurations
B_k^i	k -th non-overlapping bucket of q consecutive active weeks for team i
R_k^i	k -th overlapping rolling window of q consecutive active weeks for team i
$S_{g(i),B_k^i}$	Timeslots of group $g(i)$ in the active weeks of bucket B_k^i
H_{i,B_k^i}	Home timeslots of team i in bucket B_k^i
$S_{g(i),R_k^i}$	Timeslots of group $g(i)$ in the active weeks of rolling window R_k^i
H_{i,R_k^i}	Home timeslots of team i in rolling window R_k^i

Fixed bucket minimum constraints: The first family of constraints requires each team to play at least m home matches and at least m away matches within every non-overlapping bucket of q active weeks. By requiring at least one home and one away match in every bucket, the constraint prevents the solver from concentrating same-direction matches in a single segment of the season. This distributional spread limits the conditions under which long consecutive same-direction runs can arise and makes fixed bucket minimum constraints feasible at parameter settings where rolling window variants are not, as the non-overlapping structure generates fewer instantiated constraints and is less likely to conflict with other constraints.

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{i,B_k^i}} x_{i,j,s} \geq m \quad \forall i \in T, \forall k : |H_{i,B_k^i}| \geq m \quad (18)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g(i),B_k^i} \setminus H_{i,B_k^i}} x_{j,i,s} \geq m \quad \forall i \in T, \forall k : |S_{g(i),B_k^i} \setminus H_{i,B_k^i}| \geq m \quad (19)$$

Each direction is evaluated independently: Constraint (18) is instantiated for a given team–bucket pair only when at least m home timeslots are available within that bucket, and Constraint (19) only when at least m away timeslots are available. Instantiating a constraint for which fewer than m candidate opportunities exist would introduce a structurally infeasible row into the model, one that cannot be satisfied regardless of the values assigned to the decision variables. Such instances are therefore omitted.

Rolling window minimum constraints: The rolling window variant applies the same minimum requirement over overlapping windows of q consecutive active weeks. Because consecutive windows share $q - 1$ active weeks, this formulation imposes a stricter local regularity condition than the fixed bucket variant: every shift of one active week must still contain at least m home and at least m away matches.

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{i,R_k^i}} x_{i,j,s} \geq m \quad \forall i \in T, \forall k : |H_{i,R_k^i}| \geq m \quad (20)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g(i),R_k^i} \setminus H_{i,R_k^i}} x_{j,i,s} \geq m \quad \forall i \in T, \forall k : |S_{g(i),R_k^i} \setminus H_{i,R_k^i}| \geq m \quad (21)$$

An inherent limitation of the fixed bucket formulation is that consecutive same-direction matches can accumulate across a bucket boundary without violating any individual bucket constraint. For instance, if a team plays home matches in the final two active weeks of bucket k and the first two active weeks of bucket $k + 1$, each bucket registers only two home matches and neither constraint is violated, yet a run of four consecutive home assignments has occurred. Rolling windows eliminate this boundary effect: because every q consecutive active weeks constitute their own window, any run of same-direction matches of length q or more will be captured by at least one window constraint, regardless of where it is positioned.

Fixed bucket maximum constraints: The second family of constraints bounds the number of home matches and the number of away matches within any non-overlapping bucket of q active weeks to at most M . Whereas the minimum constraints prevent long stretches without any home or away fixtures, the maximum constraints prevent excessive accumulation of same-direction fixtures within a short window. This makes it structurally impossible for the solver to produce runs of more than M consecutive home or away matches within any bucket. However, same-direction runs that span a bucket boundary are not directly captured by this constraint. The rolling window variant addresses this limitation.

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{i,B_k^i}} x_{i,j,s} \leq M \quad \forall i \in T, \forall k : |H_{i,B_k^i}| > M \quad (22)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g(i),B_k^i} \setminus H_{i,B_k^i}} x_{j,i,s} \leq M \quad \forall i \in T, \forall k : |S_{g(i),B_k^i} \setminus H_{i,B_k^i}| > M \quad (23)$$

Each direction is again evaluated independently: a constraint is instantiated only when more than M candidate timeslots of the relevant type are present within the bucket, since a bound that cannot be reached is structurally redundant and contributes nothing to the model.

Rolling window maximum constraints: The rolling window variant applies the same upper bound over overlapping windows, providing a tighter local accumulation cap than the fixed bucket counterpart at equal q :

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{i,R_k^i}} x_{i,j,s} \leq M \quad \forall i \in T, \forall k : |H_{i,R_k^i}| > M \quad (24)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g(i),R_k^i} \setminus H_{i,R_k^i}} x_{j,i,s} \leq M \quad \forall i \in T, \forall k : |S_{g(i),R_k^i} \setminus H_{i,R_k^i}| > M \quad (25)$$

Combined configurations: The minimum and maximum constraint families are not mutually exclusive. A combined configuration applies both families simultaneously, and the two families are permitted to operate with independent parameter values : the bucket size q , the minimum threshold m , and the maximum cap M may each be set differently for the minimum and maximum constraint families within a single configuration. When applied jointly, both families act on the same decision variables $x_{i,j,s}$ and are added to the base model of Section 4.2.1 without modification to any other constraint.

Feasibility considerations: Minimum constraints can render the model infeasible when the available scheduling capacity within a window is insufficient to simultaneously satisfy the requirements of all teams. This tension is most acute when multiple teams of the same club share a limited pool of home timeslots: the venue capacity Constraint (4) restricts how many co-located teams may host a match at any given timeslot, and within a narrow bucket this restriction may make it impossible to jointly satisfy all minimum requirements. The severity of this tension is jointly determined by q and m : smaller values of q define narrower windows with fewer scheduling opportunities per team, while larger values of m raise the number of matches that must be accommodated within each window. In practice, the interaction between the bucket constraints and the full constraint set of the base model is sufficiently complex that the precise boundary at which a configuration transitions from feasible to infeasible cannot be determined analytically. It is instead identified empirically through systematic screening of configurations, the results of which are reported in Section 5.2.

Maximum constraints can also render the model infeasible. By capping the number of same-direction matches within each window, they reduce the set of feasible match distributions across the season. If this cap is too restrictive relative to the total number of matches a team must play per half-season, no valid distribution of fixtures across the available windows may exist. The half-season balance Constraints (8)

and (9) further restrict how home and away matches may be distributed within each half, potentially increasing this tension. The feasibility boundary for maximum constraint configurations is identified empirically rather than analytically.

4.3 Incomplete Round Robin Extension

This section presents an alternative scheduling formulation based on the Incomplete Round Robin (IRR) format. The formulation extends the base model of Section 4.2 with IRR-specific constraints and a travel distance objective, applied to the twelve multi-group divisions identified in Table 5.

The formulation builds on the integer programming model developed by Devriesere and Goossens (2025) for redesigning Belgian youth field hockey competitions. Their model uses similar decision variable structure to jointly determine opponent assignments and match scheduling within a single optimization framework. The model presented below adapts this approach to the Badminton Vlaanderen context, incorporating the competition-specific constraints of the base model (Section 4.2.1) and extending it with an opponent strength balance mechanism (Section 4.3.5).

4.3.1 Modifications to the Base Model

The IRR extension requires three modifications to the base model of Section 4.2.1. All existing constraints retain their numbering.

Sets: The set $G^{IRR} \subseteq G$ is added to the sets table of Section 4.2.1. Each element $g \in G^{IRR}$ corresponds to a former multi-group division, now treated as a single pool of opponents. The decomposition $G = G^{DRR} \cup G^{TRR} \cup G^{IRR}$ is complete and disjoint.

Set	Base model (Section 4.2)	IRR extension
G^{DRR}	All 47 groups scheduled as DRR	All 13 single-group divisions scheduled as DRR
G^{TRR}	Limburg Men's 3rd division (1 group)	Unchanged
G^{IRR}	Not defined	12 former multi-group divisions, each treated as a single group

Table 6: IRR extension sets

Forbidden dates extended to unwanted dates: Constraint (5) of the base model is extended to include $S^{unwanted}$.

$$x_{i,j,s} + x_{j,i,s} = 0 \quad \forall g \in G, \forall i, j \in T_g, i \neq j, \forall s \in F \cup K_{l(i)} \cup E_{c(i)} \cup S^{unwanted} \quad (5')$$

The set $S^{unwanted}$, previously penalized in the objective, now joins the forbidden-date sets. This change is justified by the experimental results of Section 5.2.1, which demonstrate that scheduling zero matches on unwanted dates is achievable under the DRR format. As a consequence, the original objective function of Section 4.2.1, which minimizes matches on unwanted dates, is no longer required and is replaced by the travel distance minimization introduced in Section 4.3.3.

4.3.2 IRR-Specific Parameters

δ_g^H	Number of home encounters per team in $g \in G^{IRR}$
δ_g^A	Number of away encounters per team, $\delta_g^A = \delta_g^H$
$d_{i,j}$	One-way driving distance (km) between home venues of teams i and j , symmetric ($d_{i,j} = d_{j,i}$)

Each team in an IRR group g plays exactly δ_g^H home and δ_g^A away encounters, with $\delta_g^H = \delta_g^A$. The value of δ_g^H and the resulting per-division match counts are presented in Section 3.1 and Table 5. The distance parameter $d_{i,j}$ is the same symmetric distance matrix as in Section 4.1.

4.3.3 Objective Function

The introduction of the IRR format changes the nature of the primary objective. Under DRR, travel distance is fully determined by group composition. Under IRR, the model selects opponents, making travel distance minimization both possible and meaningful.

The objective function minimizes the total round-trip driving distance across all IRR groups:

$$\min \sum_{g \in G^{IRR}} \sum_{i \in T_g} \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_i} 2 \cdot d_{i,j} \cdot x_{i,j,s} \quad (\text{IRR-obj})$$

Each scheduled encounter in which team i hosts team j on timeslot s contributes $d_{i,j}$, representing the one-way travel cost incurred by the visiting team j . The factor two converts one-way distances to round-trip distances.

4.3.4 IRR-Specific Constraints

Ten constraints are introduced for groups operating under the IRR format.

(IRR-1) Intra-club encounters forbidden:

$$\sum_{s \in H_i} x_{i,j,s} = 0 \quad \forall g \in G^{IRR}, \forall i, j \in T_g, i \neq j, c(i) = c(j) \quad (\text{IRR-1})$$

Two teams belonging to the same club may not meet in an IRR group. Article 25, paragraph 7 of the BV regulations requires the separation of teams from the same club into different groups whenever possible (Badminton Vlaanderen, 2025). The IRR formulation with a strict intra-club ban is therefore closer to the regulatory ideal than the current DRR practice, which permits intra-club encounters when a club enters more teams than there are groups in the division. This constraint also renders the early-encounter Constraints (6) and (7) of the base model redundant for IRR groups, since the only situation in which those constraints would bind is eliminated.

(IRR-2) At most one home encounter per ordered pair:

$$\sum_{s \in H_i} x_{i,j,s} \leq 1 \quad \forall g \in G^{IRR}, \forall i, j \in T_g, i \neq j \quad (\text{IRR-2})$$

Each team may host any given opponent at most once over the full season. This constraint implies that each unordered pair $\{i, j\}$ meets at most twice in total: at most once with i as the home side and at most once with j as the home side.

(IRR-3 and IRR-4) At most one encounter per pair in the first/return round:

$$\sum_{s \in S_{g,f}} (x_{i,j,s} + x_{j,i,s}) \leq 1 \quad \forall g \in G^{IRR}, \forall i, j \in T_g, i \neq j \quad (\text{IRR-3})$$

$$\sum_{s \in S_{g,r}} (x_{i,j,s} + x_{j,i,s}) \leq 1 \quad \forall g \in G^{IRR}, \forall i, j \in T_g, i \neq j \quad (\text{IRR-4})$$

Constraints (IRR-3) and (IRR-4) together ensure that at most one encounter between each pair takes place in each season half. This preserves the temporal separation inherited from the DRR format, where each season half accommodates one encounter per pair, and prevents the model from concentrating both encounters between a pair in the same half of the season.

(IRR-5 and IRR-6) Exact home/away encounter count:

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_i} x_{i,j,s} = \delta_g^H \quad \forall g \in G^{IRR}, \forall i \in T_g \quad (\text{IRR-5})$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_j} x_{j,i,s} = \delta_g^A \quad \forall g \in G^{IRR}, \forall i \in T_g \quad (\text{IRR-6})$$

Every team plays exactly δ_g^H home and δ_g^A away encounters. In the DRR format, Constraint (1) of the base model implicitly fixes the per-team encounter count at $n - 1$ home and $n - 1$ away by requiring each pair to meet exactly once in each direction. Since the IRR format does not require each pair to meet, the per-team encounter count must be specified explicitly.

(IRR-7 and IRR-8) Half-season balance:

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g,f}} x_{i,j,s} + x_{j,i,s} - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g,r}} x_{i,j,s} + x_{j,i,s} \leq 2 \quad \forall g \in G^{IRR}, \forall i \in T_g \quad (\text{IRR-7})$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g,r}} x_{i,j,s} + x_{j,i,s} - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g,f}} x_{i,j,s} + x_{j,i,s} \leq 2 \quad \forall g \in G^{IRR}, \forall i \in T_g \quad (\text{IRR-8})$$

Each team should play a near-equal number of encounters in both season halves. Strict equality between the first-round and return-round encounter counts is not always achievable. Under strict equality, each team would play exactly δ_g^H encounters per half. Since every encounter involves exactly two teams, the group-level total of first-half encounters would equal $|T_g| \cdot \delta_g^H / 2$. When $|T_g| \cdot \delta_g^H$ is odd (for instance, $|T_g| = 19$ and $\delta_g^H = 5$ yield $|T_g| \cdot \delta_g^H = 95$), this total ($|T_g| \cdot \delta_g^H / 2 = 47.5$) is not an integer, making strict equality infeasible. A bound of 1 is equally infeasible in these cases. Each team plays $2 \cdot \delta_g^H$ encounters per season, which is always even. Since the first-round and return-round counts sum to an even number, their difference must also be even. A bound of one on this difference would therefore be equivalent to requiring strict equality, which has just been shown to be infeasible. The bound of two is consequently the smallest feasible value.

(IRR-9 and IRR-10) Home/away balance in the first round:

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{i,f}} x_{i,j,s} - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{j,f}} x_{j,i,s} \leq 1 \quad \forall g \in G^{IRR}, \forall i \in T_g \quad (\text{IRR-9})$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{j,f}} x_{j,i,s} - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_{i,f}} x_{i,j,s} \leq 1 \quad \forall g \in G^{IRR}, \forall i \in T_g \quad (\text{IRR-10})$$

The difference between the number of home and away encounters in the first round may not exceed one. Constraints (IRR-9) and (IRR-10) are defined only for the first round. The return-round home/away balance is implied by Constraints (IRR-5) and (IRR-6) in combination with (IRR-9) and (IRR-10). Constraint (IRR-5) fixes the total number of home encounters at δ_g^H , so the return-round home count equals δ_g^H minus the first-round home count. Constraint (IRR-6) similarly fixes the total away count at $\delta_g^A = \delta_g^H$, so the return-round away count equals δ_g^H minus the first-round away count. The home/away imbalance in the return round is therefore equal in magnitude but opposite in sign to the first-round imbalance, and bounding the latter suffices. This mirrors the approach taken for Constraints (8) and (9) of the base model.

Constraints inherited from the base model:

Several constraints from the base model apply to IRR groups through their existing $\forall g \in G$ quantifier and require no modification. Teams in IRR groups are limited to at most one encounter per ISO week, venue capacity per club per timeslot is enforced jointly across all formats, and encounters on forbidden and unwanted dates are prohibited as specified in the modified Constraint (5). The venue capacity constraint is the only inter-division coupling constraint in the model: it spans all groups that share a club venue, regardless of format. This coupling plays a central role in the solution approach described in Section 4.3.6. The intra-club early-encounter Constraints (6) and (7) also extend to IRR groups but have no effect, since Constraint (IRR-1) prevents intra-club encounters entirely.

4.3.5 Opponent Strength Balance

Under the IRR format, teams play only a subset of the available opponents in their division. The scheduling model selects this subset to minimize travel distance, which may cause some teams to face systematically stronger or weaker opposition than others. This asymmetry affects the fairness of the competition standings and is a central concern in the theoretical literature on incomplete tournaments. The constraints introduced below bound the dispersion of aggregate opponent strength within each IRR group through a tolerance parameter that controls the permitted degree of imbalance.

Parameters:

$\theta_i \in \mathbb{N}$	Strength index of team i , a lower value indicates a stronger team
$\bar{\theta}_g \in \mathbb{R}^+$	Mean strength index across all teams in group $g \in G^{IRR}$, defined as $\bar{\theta}_g = \frac{\sum_{i \in T_g} \theta_i}{ T_g }$
$\alpha \in \mathbb{R}_{\geq 0}$	Tolerance parameter controlling the maximum permitted relative strength dispersion, applied uniformly across all IRR groups

The strength index θ_i is a value derived from the national rankings of individual players on each team's roster, as published by Badminton Vlaanderen. This differs from the approach of Fronček (2013), who defines team strength based on final standings in the preceding season. The use of player-level ranking data provides a more accurate reflection of current team strength in the amateur context of BV interclub competitions, where team composition can change substantially between seasons.

Decision variables and derived expressions:

$u_g \in \mathbb{R}_{\geq 0}$	Upper bound of the aggregate opponent strength in group $g \in G^{IRR}$
$l_g \in \mathbb{R}_{\geq 0}$	Lower bound of the aggregate opponent strength in group $g \in G^{IRR}$
$\Theta_i \in \mathbb{R}_{\geq 0}$	Total opponent strength index of team $i \in T_g$, with $g \in G^{IRR}$, a linear expression in the existing decision variables $x_{i,j,s}$

Θ_i is defined as:

$$\Theta_i = \sum_{\substack{j \in T_g \\ j \neq i}} \theta_j \cdot \left(\sum_{s \in H_i} x_{i,j,s} + \sum_{s \in H_j} x_{j,i,s} \right)$$

The inner term counts the total number of encounters between teams i and j (0, 1, or 2, given Constraint IRR-2). The expression is used in Constraints (STR-1) and (STR-2) below.

Constraints:

(STR-1) Upper envelope

$$u_g \geq \Theta_i \quad \forall g \in G^{IRR}, \forall i \in T_g \quad (\text{STR-1})$$

(STR-2) Lower envelope

$$l_g \leq \Theta_i \quad \forall g \in G^{IRR}, \forall i \in T_g \quad (\text{STR-2})$$

(STR-3) Dispersion bound

$$u_g - l_g \leq \alpha \cdot \bar{\theta}_g \quad \forall g \in G^{IRR} \quad (\text{STR-3})$$

The difference $u_g - l_g$ is referred to as the dispersion of group g and measures the spread in aggregate opponent strength within the group. Constraint (STR-3) bounds this dispersion relative to the group mean: a value of $\alpha = 1.0$ permits a dispersion equal to $\bar{\theta}_g$.

Connection to the epsilon-constraint method: Varying α across successive solver runs produces a set of solutions that trace the Pareto front between travel distance and opponent strength balance. This approach is an instance of the epsilon-constraint method (ECM) introduced by Haimes (1971). The primary objective (minimize total round-trip travel distance) is retained in the objective function, while the secondary objective (minimize opponent strength dispersion) is converted into a hard constraint bounded by $\alpha \cdot \bar{\theta}_g$ (STR-3). Each value of α yields one point on the Pareto front. Li (2024) applies the same method in a multi-league scheduling context, with total travel distance as the primary objective and total venue

capacity violations as the secondary objective. In the present formulation, the bound $\alpha \cdot \bar{\theta}_g$ takes continuous values, so the front is sampled at discrete α values.

Calibration of the α sweep: The range of α values used in the Pareto sweep is determined empirically. First, the unconstrained solution (obtained without Constraints STR-1 through STR-3) is analyzed: for each IRR group, the relative dispersion $(u_g - l_g)/\bar{\theta}_g$ is computed from the realized opponent assignments. The maximum observed value across all twelve groups establishes an upper bound for the sweep, since any α at or above this value is non-binding for all groups and produces the same solution as the unconstrained case.

To determine a lower bound, a separate model variant is solved in which α is treated as a decision variable rather than a parameter. The travel distance objective of Section 4.3.3 is replaced by

$$\min \alpha$$

subject to Constraints (STR-1), (STR-2), and a modified version of (STR-3) in which α appears as a variable instead of a parameter:

$$u_g - l_g \leq \alpha \cdot \bar{\theta}_g \quad \forall g \in G^{IRR} \quad (\text{STR-3}')$$

All remaining constraints of the IRR formulation are retained. This variant identifies the smallest feasible α value, establishing the left endpoint of the Pareto front. The α sweep is then restricted to the interval between these two bounds, concentrating computational effort on the range where the trade-off between travel distance and strength balance is active. Within this interval, six intermediate α values are tested: 2, 1.5, 1, 0.75, 0.5, and 0.4. The spacing is non-uniform by design: smaller increments are used in the lower region of the interval, where the Pareto front is expected to exhibit the steepest trade-off and closer sampling is therefore applied here. Together with the two extreme solutions, this yields eight configurations in total. The specific results for each configuration are reported in Section 5.3.

4.3.6 Solution Approach

The IRR extension replaces the 34 DRR groups that belonged to the twelve multi-group divisions with twelve IRR groups, one per former division. The remaining 13 single-group DRR groups and the single TRR group are unchanged. The combined model therefore contains 13 DRR groups, 1 TRR group, and 12 IRR groups for a total of 26 scheduling units spanning 317 teams.

Three approaches for solving this combined model were considered: a monolithic approach, a three-phase decomposition, and a two-phase decomposition. Each was evaluated in two settings: the base case without strength balance constraints, and a constrained case with $\alpha = 0.75$. This value represents a

demanding test case in which the strength balance constraints substantially tighten the feasible region. The results of this comparison determine the approach used for the full Pareto sweep of Section 5.3.

Monolithic approach: This approach solves all 26 groups simultaneously in a single MIP. All constraints from Sections 4.3.1 through 4.3.5 are present in one model, and the solver handles all interdependencies, including venue capacity sharing, internally.

Three-phase decomposition: This approach partitions the problem into three sequential phases based on tournament format and competition type.

Phase 1 solves all DRR and TRR groups (13 DRR + 1 TRR = 14 groups, 96 teams). Since travel distances for these groups are fully determined by the group composition of Section 4.1, this phase has no travel distance objective and reduces to a feasibility problem. All decision variables from Phase 1 are fixed before proceeding.

Phase 2A solves all Men's and Women's IRR divisions (8 divisions, 157 teams) as a single MIP, minimizing total round-trip travel distance. The venue capacity Constraint (4) uses the residual capacity from Phase 1, restricted to even-numbered weeks.

Phase 2B solves all Mixed IRR divisions (4 divisions, 64 teams) as a single MIP with the same objective. Residual capacity from Phase 1 is restricted to odd-numbered weeks. Across all configurations tested, the residual capacity was sufficient to produce a feasible IRR schedule.

The separation of Phases 2A and 2B rests on the alternating-week structure of the BV competition: Men's and Women's teams play in even ISO weeks only, while Mixed teams play in odd ISO weeks only. The venue capacity Constraint (4) is the only inter-division coupling constraint in the model. Because timeslots in even ISO weeks and odd ISO weeks form disjoint sets, this constraint never sums variables from both phases simultaneously: the solution of Phase 2A imposes no constraints on Phase 2B, and vice versa. The two phases are therefore fully independent subproblems, and their combined solution is optimal given the fixed variable assignments from Phase 1.

This decomposition has one structural limitation. Phase 1 solves DRR and TRR groups without awareness of IRR scheduling needs, so the residual venue capacity available for Phases 2A and 2B is not travel-distance-aware. In principle, rearranging DRR fixtures to free venue capacity on specific timeslots could enable better IRR matchups. This coupling is not exploited by the three-phase decomposition but would be internalized by the two-phase alternative described next.

Two-phase decomposition: This alternative also exploits the alternating-week structure, but applies it as the sole partitioning criterion. Phase 1 solves all groups scheduled in even weeks jointly: the DRR and TRR groups assigned to even weeks, together with all 8 Men’s and Women’s IRR divisions. Phase 2 solves all groups scheduled in odd weeks: the remaining DRR groups assigned to odd weeks, together with all 4 Mixed IRR divisions. By including DRR and IRR groups of the same week type in a single phase, this approach internalizes the venue capacity coupling: the solver can rearrange DRR fixtures to free capacity for cheaper IRR matchups.

Empirical comparison: Table 7 compares the three approaches in the base case (no strength balance constraints).

Metric	Monolithic	Three-phase	Two-phase
Total IRR distance (km)	84,348	84,350	84,348
Status	Optimal	Optimal	Optimal
Total solve time (s)	11,663	936	108

Table 7: Base case results for all three solution approaches

All three approaches reach proven optimality and converge to within 2 km of each other. The 2 km difference (0.0024%) is consistent with the structural limitation of the three-phase decomposition identified above. The two-phase decomposition is fastest, solving in under two minutes. The three-phase decomposition is approximately twelve times faster than the monolithic approach, which requires over three hours to certify optimality.

Table 8 compares the three approaches under the strength balance constraint at $\alpha = 0.75$. The monolithic model receives a total time limit of six hours. For the two-phase decomposition, each phase receives a time limit of three hours. For the three-phase decomposition, Phase 1 solves to optimality in under four seconds, after which Phases 2A and 2B each receive a time limit of three hours. The total computational budget is therefore comparable across all three approaches.

The time budget distribution has different practical consequences for each decomposition. In the three-phase decomposition, Phases 2A and 2B each dedicate their full three-hour budget exclusively to the IRR travel distance optimization, since Phase 1 has already resolved all DRR and TRR scheduling decisions. In the two-phase decomposition, Phase 1 must solve DRR, TRR, and IRR variables jointly within its three-hour budget, sharing solver effort between the DRR/TRR feasibility requirements and the IRR travel distance optimization.

Metric	Monolithic	Three-phase	Two-phase
Total IRR distance (km)	87,876	87,400	141,440
Status	Feasible	Feasible	Feasible
Time limit	6 h	3.5s (P1) + 3h (P2A) + 3h (P2B)	3 h (P1) + 3 h (P2)
MIP gap (%)	2.64	2.90 (P2A) / 0.71 (P2B)	50.3 (P1) / 0.53 (P2)

Table 8: Results for all three solution approaches, $\alpha = 0.75$

Unlike the base case, where all three approaches reach proven optimality, the strength balance constraints couple all assignment decisions within each division through the opponent strength expressions Θ_i and the shared decision variables u_g and ℓ_g , making the problem significantly harder to solve to proven optimality within the imposed time limits.

The three-phase decomposition produces the best incumbent (87,400 km), outperforming the monolithic model by 476 km. The monolithic model reports a slightly lower gap (2.64%) compared to phase 2A (2.90%), but this applies to a single aggregated model, whereas the decomposition concentrates its computational effort on the harder even-week subproblem separately from the easier odd-week subproblem.

The two-phase decomposition produces an incumbent that is 62% worse than the three-phase result. Because Phase 1 includes all DRR and TRR variables alongside the IRR variables for even weeks, the solver must satisfy all DRR and TRR constraints within the same three-hour budget that is also needed for the IRR travel distance optimization. The resulting Phase 1 MIP gap of 50.3% confirms that three hours is insufficient for the combined model to converge. The monolithic approach does not suffer from this particular issue because its six-hour budget is not partitioned across phases, but it converges slowly nonetheless: after three hours, it reports an incumbent of 114,072 km with a MIP gap of 25.00%, confirming that a three-hour budget is insufficient to approach optimality regardless of the solution approach.

Adopted approach: Based on these results, the three-phase decomposition is adopted for all subsequent experiments. It is the only approach that combines proven optimality in the base case with the best incumbent quality under strength balance constraints.

Note that this decomposition differs fundamentally from the grouping-scheduling separation applied to the DRR format: it partitions the problem by competition category and week parity for computational tractability, while opponent selection and timeslot assignment remain jointly optimized within each phase.

5. Results

5.1 Grouping Problem Results

The grouping problem IP model was applied to divisions across the three relevant competition leagues. Divisions containing only a single group require no assignment decision and were excluded from the optimization. Of the 26 divisions in scope, 12 contained multiple groups and were solved by the IP model. The remaining 14 required no assignment decision.

The 3rd division of Men's Competition in Limburg operates as a single Triple Round Robin group and is therefore not subject to grouping optimization. Because its individual travel distances depend on the scheduling phase rather than on group composition alone, unlike the DRR case, this group is excluded from all travel distance analyses below to maintain a consistent basis of comparison.

All optimizations reported in this chapter were conducted in Java using IBM ILOG CPLEX Optimization Studio 22.1.1 on a Windows 10 computer equipped with an Intel Core i7-7700HQ CPU running at 2.80 GHz. A time limit of 300 seconds and MIP gap tolerance of 0.1% were imposed per division. All 12 instances were solved to proven optimality, in most cases within a few seconds. The largest instance, corresponding to the Men's 3rd Liga division with 36 teams distributed across 5 groups, required 58.7 seconds. This outcome confirms that the compact formulation F1 by Toffolo et al. (2019), as adapted for the BV context, constitutes an appropriate solution method for the instances at hand.

As described in Section 3.1.4, grouping practices differ by competition level: Liga groups are composed with geographic proximity in mind, while Provincial groups are formed by lottery. This distinction is directly reflected in the magnitude of improvement reported below. In both cases, the primary motivation for applying the grouping problem model is not to critique existing practice but to establish a travel-distance-optimized baseline for the current Double Round Robin structure, against which the Incomplete Round Robin format can subsequently be evaluated on equal terms.

5.1.1 Aggregate Results

Across all relevant divisions, excluding the Triple Round Robin group, the optimized assignments reduce total travel distance from 157,684 km to 145,688 km, an aggregate reduction of 11,996 km (7.61%). Since the 14 single-group divisions are not optimized, this saving is concentrated entirely in the 12 multi-group divisions, where the distance decreases from 108,180 km to 96,184 km, a reduction of 11.09%. These figures correspond directly to the objective function value, which accounts for the full round-trip travel cost of both fixtures per co-grouped pair as described in Section 4.1.

Tables 9 and 10 summarize the aggregate travel distance results across the three relevant competition leagues. Table 9 covers all divisions, providing a complete picture of the scope of the analysis, while Table 10 isolates the 12 multi-group divisions to which the IP model was actually applied.

As shown in Table 9, the Liga Competition and the VVBBC Provincial Competition each contain multiple divisions with more than one group, and both benefit from the optimization. The Provincial Competition of Limburg, by contrast, contains no multi-group division and is therefore unaffected by the optimization.

Table 10 reveals the pure optimization effect by excluding single-group divisions, whose distances are identical in both scenarios and would otherwise dilute the comparison. The contrast between the two optimized leagues is pronounced: the VVBBC provincial divisions achieve a reduction of 9,896 km (25.59%), while the Liga divisions yield a more modest reduction of 2,100 km (3.02%), consistent with the difference in grouping methodology described in Section 3.1.4.

League	Total divisions	Single-group divisions	Multi-group divisions	Original total (km)	Optimized total (km)	Saving (km)	Improvement (%)
Liga	9	3	6	87,332	85,232	2,100	2.40
VVBBC	12	6	6	62,596	52,700	9,896	15.81
Limburg	4	4	0	7,756	7,756	0	0.00
Total	25	13	12	157,684	145,688	11,996	7.61

Table 9: Aggregate travel distance results for all divisions (excluding 3rd division of Men's Competition in Limburg)

League	Multi-group divisions	Original total (km)	Optimized total (km)	Saving (km)	Improvement (%)
Liga	6	69,508	67,408	2,100	3.02
VVBBC	6	38,672	28,776	9,896	25.59
Total	12	108,180	96,184	11,996	11.09

Table 10: Aggregate travel distance results for multi-group divisions only

5.1.2 Division-Level Analysis

Table 11 presents the travel distance results at the division level for all 12 multi-group divisions, ranked by improvement percentage. The results confirm and refine the pattern already observed at the aggregate level in Section 5.1.1: the degree of improvement varies substantially across divisions and is closely associated with the competition league to which a division belongs.

The three VVBBC Men's provincial divisions achieve the largest reductions (33.45% to 35.53%), and the remaining VVBBC divisions improve by 6.61% to 18.34%. The six Liga divisions show considerably more

modest reductions (0.00% to 7.43%), with the 2nd Liga Women's and 2nd Liga Mixed divisions already optimal with respect to total travel distance under the original grouping. This contrast reflects the difference in grouping methodology described in Section 3.1.4: Liga groups are already composed with geographic proximity in mind, leaving limited residual inefficiency, whereas the provincial lottery groups are not.

League	Division	Type	Groups	Teams	Original (km)	Optimized (km)	Saving (km)	Improvement (%)
VVBBC	3rd	M	3	20	7,724	4,980	2,744	35.53
VVBBC	5th	M	3	20	7,104	4,628	2,476	34.85
VVBBC	4th	M	3	19	8,072	5,372	2,700	33.45
VVBBC	5th	MX	2	10	3,380	2,760	620	18.34
VVBBC	4th	MX	2	14	6,764	5,780	984	14.55
Liga	3rd	MX	4	26	12,280	11,368	912	7.43
VVBBC	2nd	M	2	12	5,628	5,256	372	6.61
Liga	3rd	M	5	36	18,348	17,264	1,084	5.91
Liga	2nd	M	2	14	11,300	11,224	76	0.67
Liga	3rd	W	4	24	10,216	10,188	28	0.27
Liga	2nd	W	2	12	6,200	6,200	0	0.00
Liga	2nd	MX	2	14	11,164	11,164	0	0.00
Total				221	108,180	96,184	11,996	11.09

Table 11: Travel distance results per division for all multi-group divisions, ranked by improvement percentage

5.1.3 Team-Level Analysis

While the division-level results reported in Section 5.1.2 capture the aggregate effect of the optimization, they do not reflect how individual teams are affected. Across all 221 teams in multi-group divisions, the average individual travel distance decreases from 489.5 km to 435.2 km, a reduction of 54.3 km per team. As Table 12 shows, a majority of teams (57.0%) benefit from the optimization, while a minority (19.9%) are worse off and the remainder are unaffected.

Outcome	Number of teams	Share (%)	Average distance change (km)
Better (distance reduced)	126	57.0	-120.9
Worse (distance increased)	44	19.9	+73.5
Unchanged	51	23.1	0
Total	221	100	-54.3

Table 12: Individual total travel distance for teams in multi-group divisions

Because group sizes within a division may differ by one team, a higher total individual distance may partly reflect an additional away fixture rather than a less favorable geographic neighborhood. To control for this, the average distance per opponent is computed as a size-normalized measure of proximity. On this metric, the average distance per opponent decreases from 87.7 km to 78.2 km (10.8%), and the Better/Worse/Unchanged classification (Table 13) is nearly identical to that based on total distance.

Outcome	Number of teams	Share (%)	Average change in distance per opponent (km)
Better (avg distance reduced)	124	56.1	-21.6
Worse (avg distance increased)	46	20.8	+12.5
Unchanged	51	23.1	0.0
Total	221	100	-9.5

Table 13: Individual average travel distance per opponent for teams in multi-group divisions

The presence of teams that are worse off under the optimized grouping, regardless of which metric is used, is an inherent consequence of the sum-minimization objective: minimizing total travel distance across all groups within a division can reduce travel for some teams while increasing it for others, as long as the net divisional effect is favorable. The model does not impose any constraint on the maximum or minimum individual travel distance, and no guarantee is provided that every team benefits from the reallocation. This represents a limitation of the current formulation from a fairness perspective and deserves attention in the context of practical adoption by Badminton Vlaanderen.

A structural source of individual disadvantage that persists even after optimization is the club-separation Constraint (GRP-3), which forces the teams of a multi-entry club into different groups and therefore places at least one of them in a geographically more distant group. Table 14 illustrates this for the two multi-entry clubs in the largest solved instance, the 3rd Liga Men's Competition: despite the optimization, both De Mintons 2H and Dijlevallei 4H still travel considerably further than their clubmates, and Dijlevallei 4H is even worse off than before. The IP model thus minimizes total travel distance subject to the separation constraint but cannot eliminate the structural penalty on multi-entry clubs, which provides one of the motivations for exploring the Incomplete Round Robin format.

Team	Original total (km)	Optimized total (km)	Total change (km)	Original avg/opp (km)	Optimized avg/opp (km)	Avg/opp change (km)
De Minton 1H	632	522	-110	105.3	87.0	-18.3
De Minton 2H	800	708	-92	133.3	118.0	-15.3
Dijlevallei 3H	426	366	-60	71.0	52.3	-18.7
Dijlevallei 4H	720	772	+52	120.0	128.7	+8.7

Table 14: Individual travel distances for teams belonging to clubs with multiple teams in the 3rd Liga Men's Competition, original versus optimized grouping

A further fairness consideration concerns the team carrying the highest individual travel burden within each division. Because group sizes within a division may differ by one team, as discussed above, the average distance per opponent is used as the basis for this comparison. Table 15 reports, for each multi-group division, the maximum average distance per opponent observed before and after optimization, along with the identity of the team bearing that burden. It is important to note that the team with the highest average distance per opponent may differ between the original and optimized assignment, as the reallocation of teams across groups may shift the burden from one team to another. A direct comparison of the maximum values therefore does not necessarily reflect the trajectory of a single team, but rather characterizes the worst-case individual outcome within a division under each scenario.

League	Division	Type	Original max team	Original max (km)	Optimal max team	Optimal max (km)	Change (km)
VVBBC	2nd	M	Herne 3H	153.2	Tienen 2H	131.2	-22.0
VVBBC	3rd	M	Halle 3H	100.0	Nero's BC 1H	78.8	-21.2
VVBBC	4th	M	Leeuwse 1H	111.2	BaZo 3H	103.7	-7.5
VVBBC	4th	MX	BaZo 2G	132.3	Halle 1G	128.7	-3.7
VVBBC	5th	M	Leeuwse 2H	96.0	Halle 4H	56.4	-39.6
VVBBC	5th	MX	Herne 3G	155.0	Herne 3G	125.5	-29.5
Liga	2nd	W	Pluimplukkers 2D	184.0	Pluimplukkers 3D	184.0	0.0
Liga	2nd	M	Brugse 1H	164.7	Brasschaat 1H	185.7	+21.0
Liga	2nd	MX	Looise 2G	252.7	Looise 2G	252.7	0.0
Liga	3rd	W	De Bokkerijder 1D	139.6	De Bokkerijder 1D	142.0	+2.4
Liga	3rd	M	Westhoek 1H	144.3	Westhoek 1H	144.3	0.0
Liga	3rd	MX	Westhoek 1G	163.3	Westhoek 1G	163.3	0.0

Table 15: Maximum average distance per opponent per multi-group division, original versus optimized grouping

Across the 12 multi-group divisions, the maximum individual distance per opponent improves in 6 cases, is unchanged in 4, and worsens in 2, with the average divisional maximum decreasing from 149.7 km to

141.4 km. Both deteriorations occur in Liga divisions. These cases confirm that sum minimization does not rule out individually disadvantaged teams, and that the fairness implications of group composition extend beyond aggregate totals.

5.2 Scheduling Results

This section presents the results of applying the integer programming model described in Section 4.2 to the Badminton Vlaanderen interclub competition for the 2025–2026 season. The schedule is constructed using the optimized group composition resulting from the model described in Section 4.1. The scheduling model guarantees satisfaction of all hard requirements of Section 3.1.2, and quality is assessed on the two criteria of Section 3.1.3: unwanted matches and triple breaks. As described in Section 4.2, these are addressed through distinct mechanisms, the objective function for unwanted matches and the bucket constraints for triple breaks. To assess the contribution of each, a set of 21 configurations is evaluated, varying the bucket constraints, their parameters, and the activation of the objective function.

5.2.1 Experimental Results

Before analyzing schedule quality, a feasibility screening is conducted across all 21 experimental configurations. Each configuration applies one constraint family (Fixed Min, Fixed Max, Rolling Min, or Rolling Max) or a combination of them, together with the specific values assigned to the bucket size parameter q , the minimum threshold m , and the maximum cap M . Runs R17, R18, and R19 share the same constraint families and parameter values as R15 but deactivate the objective function and instead impose a hard upper bound on the number of unwanted matches. These runs are included for the trade-off analysis later in this section.

Of the 21 configurations evaluated, 14 prove feasible and all 14 solve to proven optimality (gap = 0%). The remaining 7 configurations are infeasible. Table 16 reports the full results.

Run	Constraint families	q	m	M	Obj.	UM cap	Status
R0	None	—	—	—	On	—	OPTIMAL
R1	Fixed Min	4	≥ 1	—	On	—	INFEASIBLE
R2	Fixed Min	5	≥ 1	—	On	—	OPTIMAL
R3	Rolling Min	5	≥ 1	—	On	—	INFEASIBLE
R4	Rolling Min	6	≥ 1	—	On	—	OPTIMAL
R5	Fixed Max	4	—	≤ 2	On	—	OPTIMAL
R6	Fixed Max	5	—	≤ 2	On	—	INFEASIBLE
R7	Rolling Max	3	—	≤ 2	On	—	INFEASIBLE
R8	Rolling Max	5	—	≤ 3	On	—	OPTIMAL
R9	Rolling Max	6	—	≤ 3	On	—	INFEASIBLE
R10	Fixed Min + Fixed Max	5 / 4	≥ 1	≤ 2	On	—	OPTIMAL
R11	Rolling Min + Fixed Max	6 / 4	≥ 1	≤ 2	On	—	INFEASIBLE
R12	Fixed Min + Rolling Max	5 / 5	≥ 1	≤ 3	On	—	OPTIMAL
R13	Rolling Min + Rolling Max	6 / 5	≥ 1	≤ 3	On	—	OPTIMAL
R14	Fixed Min + Fixed Max	5 / 5	≥ 1	≤ 3	On	—	OPTIMAL
R15	Fixed Min + Fixed Max + Rolling Max	5 / 4 / 5	≥ 1	$\leq 2 / \leq 3$	On	—	OPTIMAL
R16	Fixed Min + Rolling Min + Fixed Max	5 / 6 / 4	≥ 1	≤ 2	On	—	INFEASIBLE
R17	Fixed Min + Fixed Max + Rolling Max	5 / 4 / 5	≥ 1	$\leq 2 / \leq 3$	Off	≤ 5	OPTIMAL
R18	Fixed Min + Fixed Max + Rolling Max	5 / 4 / 5	≥ 1	$\leq 2 / \leq 3$	Off	≤ 25	OPTIMAL
R19	Fixed Min + Fixed Max + Rolling Max	5 / 4 / 5	≥ 1	$\leq 2 / \leq 3$	Off	None	OPTIMAL
R20	None	—	—	—	Off	None	OPTIMAL

Table 16: Feasibility outcomes for all 21 experimental configurations

As discussed in Section 4.2.2, the feasibility outcomes cannot be predicted analytically: configurations from the same family but with different parameters can yield opposite outcomes, and combined configurations may be infeasible even when both constituent families are individually feasible. Rolling window constraints amplify this risk, since their overlapping structure instantiates substantially more constraints than the fixed bucket counterpart at equal q .

The infeasibility of R7, which applies Rolling Max with $q=3$ and $M \leq 2$, carries a further implication for schedule quality. This configuration requires that within any three consecutive active weeks, a team plays at most two matches in the same direction. If no feasible schedule satisfies this requirement, it follows that at least one team must inevitably be assigned three consecutive same-direction matches in some part of the season. The infeasibility of R7 therefore constitutes direct evidence that triple breaks cannot be fully eliminated from the schedule. It is worth noting, however, that this conclusion rests specifically on R7's infeasibility: had R7 been feasible, its feasibility would not have implied that a triple-break-free schedule exists. In a time-relaxed format, a team may hold active weeks in which no encounter is assigned. A sequence such as H—[no match]—H—H constitutes three consecutive same-direction played matches but spans four timeslots, so that no single rolling window of size three captures more than two of the three

same-direction matches. The Rolling Max constraint would therefore not flag the triple break. The Rolling Max family is consequently an imperfect instrument for controlling triple breaks in this time-relaxed setting, and a feasible R7 schedule could in principle still contain triple breaks arising from such patterns.

All feasible configurations solve to proven optimality well within the 600-second time limit, with solve times ranging from 19.2 seconds (R0) to 386.1 seconds (R12). The addition of bucket constraints increases the constraint count from 18,161 in the base model to at most 33,164, but all configurations remain tractable.

The 14 feasible configurations are carried forward to the quality analysis below. Table 17 reports unwanted matches and triple breaks for all feasible configurations together with the BV reference schedule, and Figure 4 plots the same results with triple breaks on the horizontal axis and unwanted matches on the vertical axis.

Run	Constraint families	q	m	M	Obj.	UM	Triple	Unwanted
R0	None	—	—	—	On	—	374	0
R2	Fixed Min	5	≥ 1	—	On	—	291	0
R4	Rolling Min	6	≥ 1	—	On	—	303	0
R5	Fixed Max	4	—	≤ 2	On	—	246	0
R8	Rolling Max	5	—	≤ 3	On	—	348	0
R10	Fixed Min + Fixed Max	5 / 4	≥ 1	≤ 2	On	—	209	0
R12	Fixed Min + Rolling Max	5 / 5	≥ 1	≤ 3	On	—	286	0
R13	Rolling Min + Rolling Max	6 / 5	≥ 1	≤ 3	On	—	259	0
R14	Fixed Min + Fixed Max	5 / 5	≥ 1	≤ 3	On	—	290	0
R15	Fixed Min + Fixed Max + Rolling	5/4/5	≥ 1	$\leq 2/\leq 3$	On	—	189	0
R17	Fixed Min + Fixed Max + Rolling	5/4/5	≥ 1	$\leq 2/\leq 3$	Off	≤ 5	210	5
R18	Fixed Min + Fixed Max + Rolling	5/4/5	≥ 1	$\leq 2/\leq 3$	Off	≤ 25	201	24
R19	Fixed Min + Fixed Max + Rolling	5/4/5	≥ 1	$\leq 2/\leq 3$	Off	None	181	54
R20	None	—	—	—	Off	None	352	57
BV	Operational schedule 2025–2026	—	—	—	—	—	199	16

Table 17: Triple breaks and unwanted matches for all feasible configurations and the BV reference schedule

Effect of the objective function on unwanted matches: Across all feasible configurations in which the objective is active, the number of unwanted matches is zero, regardless of which bucket constraints are applied. This establishes that the objective function alone is sufficient to eliminate unwanted matches entirely. In principle a sufficiently restrictive bucket configuration could force matches onto unwanted dates, but no such tension arose for any feasible configuration tested here.

Effect of the bucket constraints on triple breaks: The baseline configuration R0, with the objective active but no bucket constraints, yields 374 triple breaks and serves as the reference for the constrained configurations. Among single-family configurations, the maximum variants outperform the minimum variants: Fixed Max reduces triple breaks more than Fixed Min. The maximum variant caps same-direction matches within a window directly, whereas the minimum variant limits accumulation only indirectly, by requiring at least one match in each direction per bucket, which leaves more room for same-direction sequences to form within and across window boundaries.

The two rolling variants produce weaker results in isolation, not because they are inherently weaker families (rolling windows impose stricter local regularity than fixed buckets at equal q), but because their tighter parameter settings render the model infeasible. The strictest rolling parameters that remain feasible are comparatively loose, which limits the reduction they can deliver alone.

Combined configurations yield further reductions with diminishing returns (Table 17). The best result among all objective-active configurations is R15, which combines Fixed Min, Fixed Max, and Rolling Max for 189 triple breaks, a reduction of 49% relative to R0. This confirms that the three families are complementary, with the rolling maximum providing additional coverage at window boundaries not captured by the fixed variants alone.

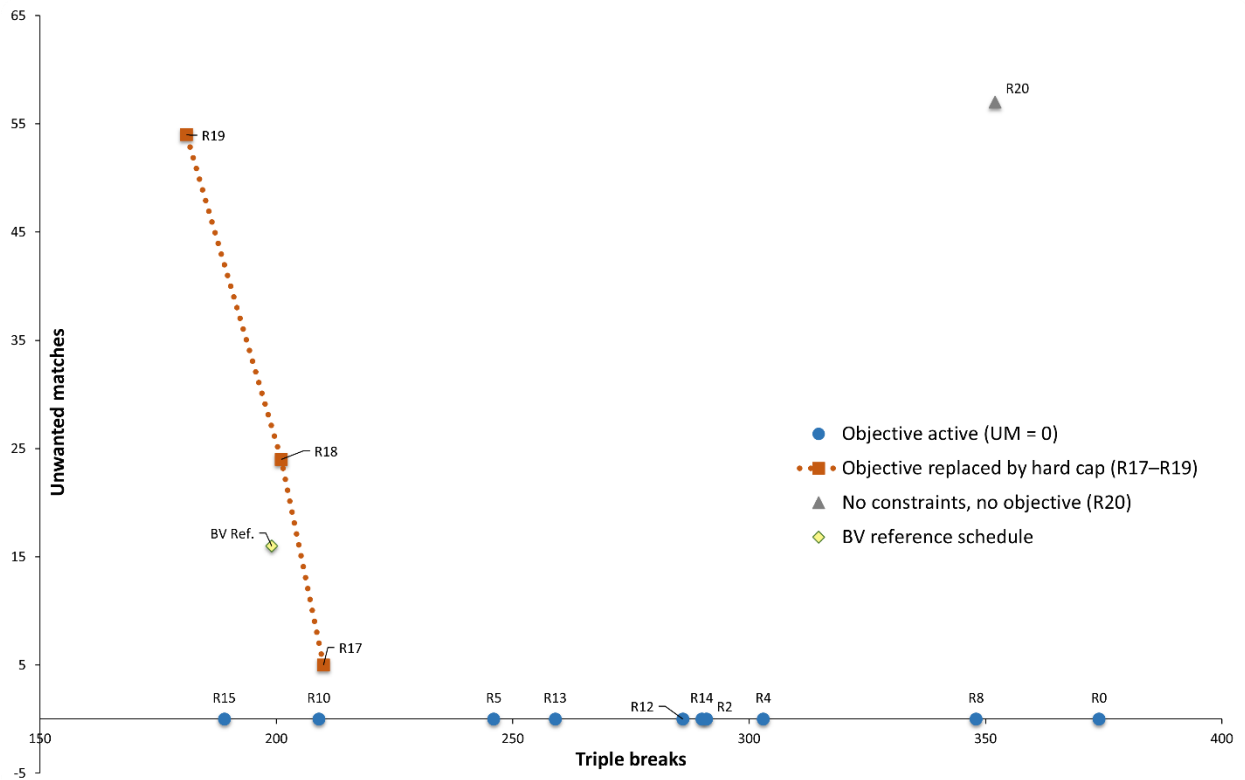


Figure 4: Quality outcomes for all feasible configurations and the BV reference schedule

Independence of the two mechanisms and the trade-off: The independence of the two mechanisms is visible in Figure 4. All objective-active configurations cluster along the horizontal axis at zero unwanted matches, spanning a wide range of triple break counts determined exclusively by the choice of bucket constraints. The objective function eliminates unwanted matches uniformly across all feasible configurations, while the bucket constraints reduce triple breaks independently of whether the objective is active.

The interaction between the two criteria is examined more directly through runs R17, R18, and R19, each of which applies the same constraint set as R15 but replaces the objective function with a hard upper bound on unwanted matches. Run R17 imposes the tightest cap (≤ 5 unwanted matches) and yields 210 triple breaks at 5 unwanted matches, which is slightly worse than R15 on triple breaks and nearly equivalent on unwanted matches. As the cap is progressively relaxed in R18 (≤ 25 unwanted matches) and R19 (no cap), the solver gains increasing freedom to redistribute matches across timeslots, allowing it to reduce triple breaks further: R18 yields 201 triple breaks at 24 unwanted matches, and R19 yields 181 triple breaks at 54 unwanted matches. Run R19 achieves the lowest triple break count of all configurations evaluated, but at the cost of 54 unwanted matches. This trade-off is one that Badminton Vlaanderen would not accept in practice, since it considers unwanted matches the more operationally significant criterion, as noted in Section 3.1.3 (Casier, 2025). Activating the objective function (R15) recovers this quality

entirely at a cost of only 8 additional triple breaks relative to R19, making it the clearly dominant configuration across both dimensions.

5.2.2 Comparison with the BV Reference Schedule

Table 18 presents a direct comparison between R0, R15, and the BV reference schedule across three quality dimensions: triple breaks and unwanted matches, analyzed in Section 5.2.1, and maximum 1 match per week violations, defined as weeks in which a team is scheduled for more than one encounter. The latter metric is included here as it emerges directly from inspecting the BV reference schedule and is structurally impossible in the model by construction.

Configuration	Triple breaks	Unwanted matches	Max. 1 match per week violations
R0 – No bucket constraints, objective active	374	0	0
R15 – Best-performing configuration	189	0	0
BV Ref. – Operational schedule 2025–2026	199	16	3

Table 18: Quality comparison across three dimensions for the unconstrained baseline, the best-performing configuration, and the BV reference schedule

R15 strictly dominates the BV reference schedule on every dimension. The reduction in triple breaks from 199 to 189 is modest, suggesting that the BV planning process already achieves a reasonable home/away distribution implicitly, even in the absence of formal constraints to that effect. The more substantial differences lie in the remaining two dimensions: R15 produces zero unwanted matches against 16 in the BV schedule, and zero max-week violations against three. The latter is particularly noteworthy. Maximum 1 match per week violations occur when a team is assigned more than one encounter in a single week, breaching the hard constraint that each team may play at most once per week. These are structurally impossible in the model by construction, whereas the BV reference schedule contains three such violations, indicating that the current planning process does not fully enforce this requirement.

This comparison should be interpreted with two considerations in mind. First, the BV reference schedule is constructed on the current group composition, while R15 operates on the optimized group composition described in Section 5.1. The comparison is therefore not fully *ceteris paribus*, and the quality differences reported above reflect both the scheduling model and the underlying group structure. Second, Badminton Vlaanderen does take undesirable dates into account in its planning process, though not through a formal

hard constraint or objective function. The 16 unwanted matches in the reference schedule are therefore attributable to the limitations of manual enforcement rather than a disregard for the criterion.

Within these caveats, the results establish that the integer programming model produces schedules of higher quality than current operational practice while providing formal guarantees that the current scheduling process does not. This concludes the analysis of the scheduling problem. The following section extends the scope of the study by examining an alternative competition format through an Incomplete Round Robin structure.

5.3 Incomplete Round Robin Results

This section reports the results of the Incomplete Round Robin (IRR) extension of Section 4.3, applied to the twelve multi-group divisions (221 teams) identified in Table 5. The travel distances of the 14 single-group divisions are unaffected and all travel distance analyses below are therefore restricted to the twelve IRR-eligible divisions.

Across the twelve divisions, the IRR schedule contains 1,249 matches against 1,230 under DRR, a net increase of 19 (+1.54%), so any travel distance reduction is obtained despite a marginally higher fixture volume. As in Section 5.1, all distances are round-trip.

All results were obtained using the three-phase decomposition adopted in Section 4.3.6, validated by the comparison in Tables 7 and 8. Phase 1 solves to optimality in under four seconds, after which Phases 2A and 2B each receive a time limit of three hours.

Travel distance is the primary objective and opponent strength dispersion the secondary one, incorporated through the epsilon-constraint method of Section 4.3.5: each value of the dispersion bound α yields one point on a Pareto front. The optimized DRR grouping from Section 5.1 (96,184 km) serves as the comparison baseline, so that any reported improvement reflects the format change rather than grouping quality.

Section 5.3.1 presents the two anchoring solutions. Section 5.3.2 reports the full Pareto sweep and identifies a recommended configuration. Section 5.3.3 provides a detailed travel distance comparison at the aggregate, division, and team levels. Section 5.3.4 examines the effect of the format change on multi-entry clubs.

5.3.1 Bounding the Solution Space

This subsection establishes the two extreme solutions that define the endpoints of the Pareto front: an unconstrained solution that minimizes travel distance without any strength balance requirement, and a

minimum- α solution that achieves the tightest strength balance the solver could achieve within the imposed time limit.

Pure travel distance minimization: The unconstrained run disables Constraints (STR-1) through (STR-3) entirely, allowing the solver to assign opponents based solely on geographic proximity. The three-phase decomposition solves to proven optimality in all phases, with a total solve time of 936.2 seconds (Phase 1: 3.5 seconds, Phase 2A: 926.2 seconds, Phase 2B: 6.5 seconds). Both Phase 2A and Phase 2B report a MIP gap of 0.00%.

The resulting total IRR travel distance is 84,350 km, a reduction of 11,834 km (12.3%) compared to the optimized DRR baseline of 96,184 km.

The relative opponent strength dispersion $(u_g - l_g)/\bar{\theta}_g$, computed retrospectively for each of the twelve IRR divisions, is reported in Table 19. It ranges from 0.685 (4th Provincial Mixed) to 2.306 (Women's 2nd Liga), with the Liga divisions exhibiting higher dispersion than the Provincial divisions: team indices are distributed less homogeneously across regions in the Liga competitions. The maximum value, 2.306, serves as the upper bound of the α sweep, since any α at or above it is non-binding for all divisions and reproduces the unconstrained solution.

League	Division	$\bar{\theta}_g$	u_g	l_g	$u_g - l_g$	Rel. dispersion
Liga	2nd Women's	33.83	370	292	78	2.306
Liga	3rd Men's	32.36	426	356	70	2.163
Liga	3rd Women's	42.21	454	372	82	1.943
Liga	2nd Mixed	44.93	572	504	68	1.514
Liga	3rd Mixed	51.69	658	580	78	1.509
Liga	2nd Men's	24.36	311	278	33	1.355
VVBBC	3rd Prov. Men's	59.60	748	684	64	1.074
VVBBC	2nd Prov. Men's	50.50	528	484	44	0.871
VVBBC	5th Prov. Men's	85.10	1,058	988	70	0.823
VVBBC	4th Prov. Men's	73.68	762	708	54	0.733
VVBBC	5th Prov. Mixed	128.70	1,350	1,257	93	0.723
VVBBC	4th Prov. Mixed	108.07	1,338	1,264	74	0.685

Table 19: Relative opponent strength dispersion per division, unconstrained IRR solution

Minimum feasible α : The minimum- α variant replaces the travel distance objective with $\min \alpha$ and imposes Constraints (STR-1), (STR-2), and (STR-3') with α as a decision variable, as described in Section 4.3.5. A single shared α must satisfy all twelve IRR divisions simultaneously, so the result is the smallest α for which the combined model is globally feasible. The three-phase decomposition terminates after a total solve time of 21,690 seconds. Phase 2A and Phase 2B each reach the three-hour time limit, both reporting a status of feasible with a MIP gap of 100%. The 100% gap arises because the LP relaxation, in which the encounter variables $x_{i,j,s}$ may take fractional values, can distribute opponent strength perfectly evenly across all teams, yielding $\alpha = 0$ at the root node. The branch-and-bound process would need to raise this lower bound above zero to close the gap, but the allotted time was insufficient for this. The incumbent solution is nevertheless informative, as it provides the best known bound on the achievable α . A tighter value might exist but would require additional computation time to identify.

The best feasible α found is 0.355. Table 20 reports the per-division dispersion values under this solution. The binding division is Women's 3rd Liga, whose relative dispersion of 0.355 matches the global α bound. All other divisions have slack: their relative dispersion values fall strictly below the imposed α bound.

The corresponding total IRR travel distance is 160,070 km, an increase of 63,886 km (+66.4%) over the optimized DRR baseline. Enforcing tight strength balance thus eliminates the travel distance advantage of the IRR format and introduces a substantial additional penalty.

League	Division	$\bar{\theta}_g$	u_g	l_g	$u_g - l_g$	Rel. dispersion
Liga	3rd Women's	42.21	431	416	15	0.355
Liga	2nd Men's	24.36	297	289	8	0.328
Liga	3rd Men's	32.36	393	383	10	0.309
VVBBC	4th Prov. Men's	73.68	748	725	23	0.312
VVBBC	5th Prov. Men's	85.10	1,034	1,009	25	0.294
VVBBC	3rd Prov. Men's	59.60	725	708	17	0.285
VVBBC	2nd Prov. Men's	50.50	513	499	14	0.277
Liga	2nd Women's	33.83	343	334	9	0.266
Liga	2nd Mixed	44.93	542	537	5	0.111
VVBBC	4th Prov. Mixed	108.07	1,303	1,292	11	0.102
VVBBC	5th Prov. Mixed	128.70	1,295	1,282	13	0.101
Liga	3rd Mixed	51.69	623	618	5	0.097

Table 20: Relative opponent strength dispersion per division, minimum- α IRR solution

Table 21 summarizes the two extreme solutions. The gap between 84,350 km and 160,070 km defines the range within which intermediate α values trade off travel distance against strength balance. Section 5.3.2 explores this trade-off through six additional configurations.

Metric	IRR unconstrained	IRR min- α
α	2.306 (realized max)	0.355 (best feasible)
Total IRR distance (km)	84,350	160,070
vs. Optimized DRR (km / %)	-11,834 / -12.3%	+63,886 / +66.4%
Binding division	Women's 2nd Liga	Women's 3rd Liga
Solve time (s)	936	21,690
MIP gap (%)	0.00	100.00

Table 21: Extreme IRR solutions defining the Pareto front endpoints

5.3.2 Pareto Front: Travel Distance versus Strength Balance

The two extreme solutions of Section 5.3.1 define the endpoints of the trade-off between travel distance and opponent strength balance. This subsection maps the full Pareto front between these endpoints through an epsilon-constraint sweep over six intermediate α values: 2, 1.5, 1, 0.75, 0.5, and 0.4. Together with the unconstrained run and the minimum- α run, this yields eight configurations.

Figure 5 plots the resulting Pareto front alongside two DRR reference points discussed below. Table 22 reports the corresponding numerical results. All configurations except $\alpha = 0.4$ and min- α achieve a total travel distance below the optimized DRR baseline of 96,184 km from Section 5.1. The MIP gap columns refer to the gap at termination for Phases 2A and 2B of the three-phase decomposition, from $\alpha = 1.5$ onward, Phase 2A reaches the three-hour time limit and the reported distances are therefore upper bounds on the true Pareto-optimal values.

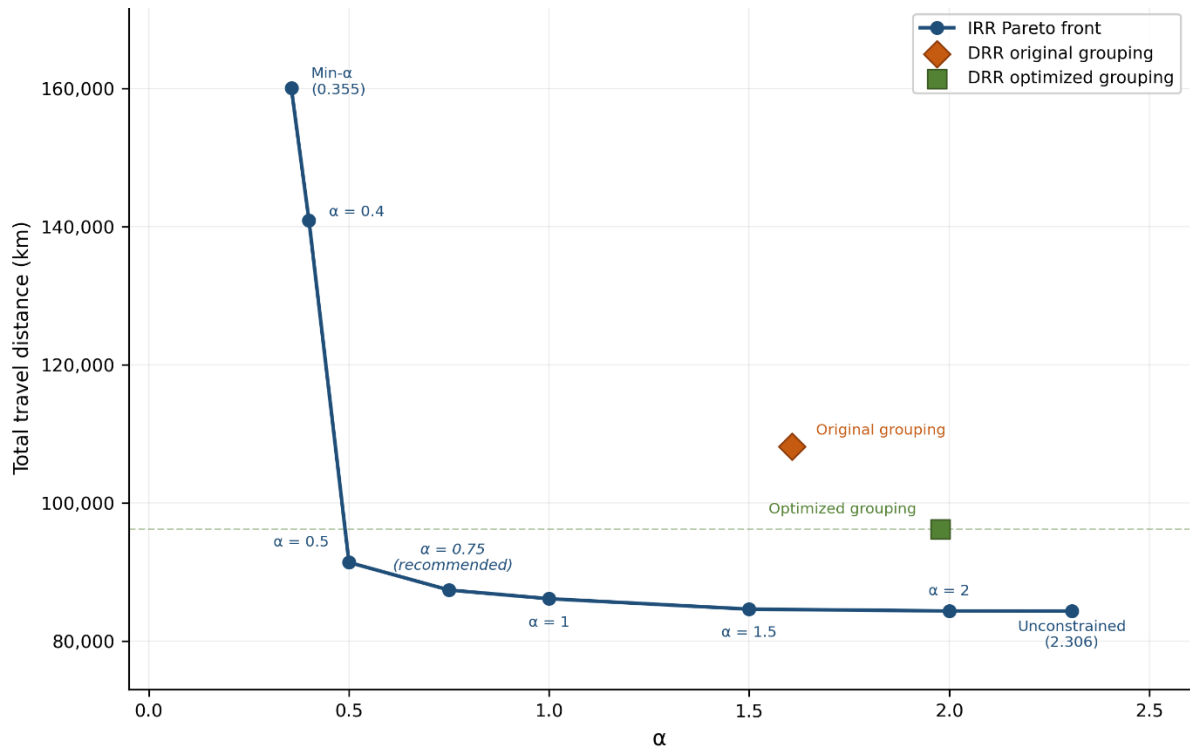


Figure 5: Pareto front of total IRR travel distance versus maximum relative opponent strength dispersion (α)

Shape of the Pareto front: The front exhibits a characteristic L-shape with two distinguishable regions. The right portion, spanning α values from the unconstrained solution down to approximately 0.5, is relatively flat: tightening the strength balance constraint across this range increases total travel distance by only 7,050 km, a modest 8.4% penalty relative to the unconstrained optimum. Below $\alpha = 0.5$, the front becomes dramatically steep: the step from $\alpha = 0.5$ to $\alpha = 0.4$ alone adds nearly 50,000 km, and the final step to the minimum- α solution adds another 19,000 km. The practical implication is that moderate α values offer a favorable compromise, achieving substantial improvements in strength balance over the unconstrained case while preserving most of the travel distance reduction that the IRR format enables.

The steep part of the front at low α values must be interpreted with caution, as the Phase 2A MIP gap increases from 6.85% at $\alpha = 0.5$ to 48.36% at $\alpha = 0.4$. The reported travel distances for tighter α values are upper bounds: the actual front may lie below the observed points, particularly in this region.

α	Total IRR distance (km)	vs. Opt. DRR (km)	vs. Opt. DRR (%)	Gap 2A (%)	Gap 2B (%)
2.306 (unconstrained)	84,350	-11,834	-12.3	0.00	0.00
2	84,370	-11,814	-12.3	0.00	0.00
1.5	84,632	-11,552	-12.0	0.14	0.00
1	86,144	-10,040	-10.4	2.17	0.13
0.75	87,400	-8,784	-9.1	2.90	0.71
0.5	91,400	-4,784	-5.0	6.85	1.61
0.4	140,936	+44,752	+46.5	48.36	2.14
0.355 (min- α)	160,070	+63,886	+66.4	100.00	100.00

Table 22: Pareto front summary for all IRR configurations

Recommended configuration: The knee of the Pareto front lies at $\alpha = 0.5$, where the curve transitions from a gradual slope to a steep ascent. However, $\alpha = 0.75$ is identified as the recommended configuration. This value lies well within the flat region of the front, where tightening the strength balance constraint incurs minimal travel cost: the total distance of 87,400 km is only 3,050 km (3.6%) above the unconstrained optimum, while the maximum realized relative dispersion across all twelve divisions drops from 2.306 to 0.746. Moving from $\alpha = 0.75$ to the knee point at $\alpha = 0.5$ would cost an additional 4,000 km for a more modest dispersion improvement. The $\alpha = 0.75$ configuration therefore captures the majority of the achievable fairness gain at a negligible travel distance cost, while retaining a comfortable margin above the knee where costs begin to escalate. Additionally, the Phase 2A MIP gap at $\alpha = 0.75$ is 2.90%, compared to 6.85% at the knee point ($\alpha = 0.5$), and is therefore a more reliable basis for comparison.

DRR reference points: To contextualize the IRR Pareto front relative to the current format, the opponent strength dispersion under DRR is computed retrospectively for both the original and the optimized groupings. Under DRR, each team plays all opponents within its group, so the total opponent strength index for each team is fully determined by the group composition. Within each division, the range between the highest and lowest total opponent strength is computed across all teams spanning all groups, and the relative dispersion is evaluated using the same formula as for the IRR divisions. The maximum across the twelve multi-group divisions serves as the DRR realized α .

An important caveat applies to this comparison. Under DRR, within-group fairness is structurally guaranteed: every team faces every other team in its group. The strength dispersion measured here therefore arises between groups within the same division, not between teams competing in a single group.

Under IRR, by contrast, the dispersion occurs within a single division-wide group where all teams' standings are directly comparable. These represent qualitatively different sources of unfairness. In a DRR competition, teams in different groups cannot compare their relative standings directly, and the between-group strength imbalance is arguably less important than it would be in a single-group format. The DRR reference points on Figure 5 should therefore be interpreted as indicative rather than strictly equivalent to the IRR data points.

With this caveat in mind, the original BV grouping yields a realized α of 1.607 at a total travel distance of 108,180 km, while the optimized grouping from Section 5.1 yields a realized α of 1.978 at 96,184 km. The optimized grouping exhibits a higher strength dispersion because the grouping model of Section 4.1 minimized travel distance without any strength balance consideration, and the resulting geographically compact groups happen to produce a less balanced distribution of team strengths across groups. Both DRR points lie above and to the right of the IRR Pareto front in Figure 5: the recommended IRR configuration ($\alpha = 0.75$) achieves a lower total travel distance and a tighter opponent strength dispersion than either DRR scenario, although this comparison should be read in light of the caveat above, and the fact that the DRR grouping problem did not take strength balance into account. A strength-aware extension of the grouping formulation could shift the DRR reference points leftward, toward lower dispersion.

5.3.3 Travel Distance Comparison with the DRR Format

The preceding subsection identified $\alpha = 0.75$ as the recommended configuration. This subsection provides a detailed comparison of travel distances at the aggregate, division, and team levels, using both the recommended IRR solution ($\alpha = 0.75$) and the unconstrained IRR solution as reference points. All comparisons use the optimized DRR grouping from Section 5.1 as the primary baseline.

Because the number of away matches differs between the two formats in six divisions (Table 5), the average distance per away match is used alongside total distance throughout this subsection, isolating the geographic effect of opponent selection from the effect of differing fixture counts.

Aggregate results: As Table 23 shows, the unconstrained IRR solution reduces total distance to 84,350 km (–12.3% versus the optimized DRR baseline of 96,184 km), and the recommended solution at $\alpha = 0.75$ to 87,400 km (–9.1%). Both improve upon the optimized DRR grouping, which itself was 11.1% below the original BV grouping.

The league-level breakdown reveals that the unconstrained and recommended IRR solutions produce nearly identical VVBBC totals (25,216 km versus 25,228 km), whereas the Liga totals diverge more substantially (59,134 km versus 62,172 km). This pattern indicates that in the provincial divisions, the

strength balance constraint at $\alpha = 0.75$ imposes almost no additional travel cost. The explanation lies in the structure of the strength indices at the provincial level: within each VVBBC division, the relative differences between team indices are smaller than in the Liga divisions, so that geographically optimal opponent assignments already satisfy the strength constraint with little or no adjustment. As a result, the choice of α primarily affects Liga divisions, where the wider spread of team strengths forces the solver to deviate from purely distance-optimal matchups to achieve balance.

Scenario	VVBBC (km)	Liga (km)	Total (km)	vs. Opt. DRR (km)	Improvement (%)
Original grouping (DRR)	38,672	69,508	108,180	+11,996	-12.5
Optimized grouping (DRR)	28,776	67,408	96,184	(baseline)	(baseline)
IRR unconstrained	25,216	59,134	84,350	-11,834	12.3
IRR recommended ($\alpha = 0.75$)	25,228	62,172	87,400	-8,784	9.1

Table 23: Aggregate travel distance comparison

Division-level analysis: Table 24 reports the travel distance per division for the recommended IRR configuration alongside the optimized DRR baseline, ranked by improvement in average distance per away match. Figure 6 visualizes this comparison. On this metric, eleven of the twelve divisions show an improvement or remain essentially unchanged under IRR. The largest absolute saving occurs in the 3rd Liga Men's division (2,484 km), which is also the largest division with 36 teams and five former DRR groups, consistent with the expectation that larger divisions benefit more from the solver's greater freedom to select geographically proximate opponents.

The 3rd Liga Mixed Competition, which appears to deteriorate by 938 km in total distance, is essentially neutral on a per-away-match basis (78.9 km under both formats). The apparent total increase is entirely attributable to the higher number of away matches under IRR (156 versus 144), not to worse opponent selection.

The 5th Provincial Mixed Competition is the only division with a meaningful deterioration in average distance per away match (+4.3 km, or +6.2%). As the smallest multi-group division (ten teams), it offers the solver little geographic flexibility, and the IRR format imposes five away encounters per team here against four under DRR, following the minimum encounter lower bound of Section 3.1. The additional away trip to a fifth opponent from a small pool drives the increase. This is a structural consequence of the

higher match count and limited divisional size, not of the strength balance constraint: the unconstrained solution produces the same average distance per away match (73.3 km) at a realized dispersion of 0.723, already below the $\alpha = 0.75$ threshold.

Division	Opt. DRR (km)	IRR rec. (km)	DRR avg/match	IRR avg/match	Impr. avg (%)
4th Prov. M	5,372	3,904	52.7	41.1	22.0
2nd Prov. M	5,256	4,196	87.6	69.9	20.2
4th Prov. MX	5,780	4,824	68.8	57.4	16.5
3rd Prov. M	4,980	4,384	43.7	36.5	16.4
5th Prov. M	4,628	4,256	40.6	35.5	12.6
2nd Liga MX	11,164	9,828	132.9	117.0	12.0
3rd Liga W	10,188	9,002	84.9	75.0	11.6
3rd Liga M	17,264	14,780	77.1	68.4	11.2
2nd Liga M	11,224	10,390	133.6	123.7	7.4
2nd Liga W	6,200	5,866	103.3	97.8	5.4
3rd Liga MX	11,368	12,306	78.9	78.9	0.1
5th Prov. MX	2,760	3,664	69.0	73.3	-6.2
Total	96,184	87,400			

Table 24: Travel distance per division, optimized DRR vs. IRR recommended ($\alpha = 0.75$)

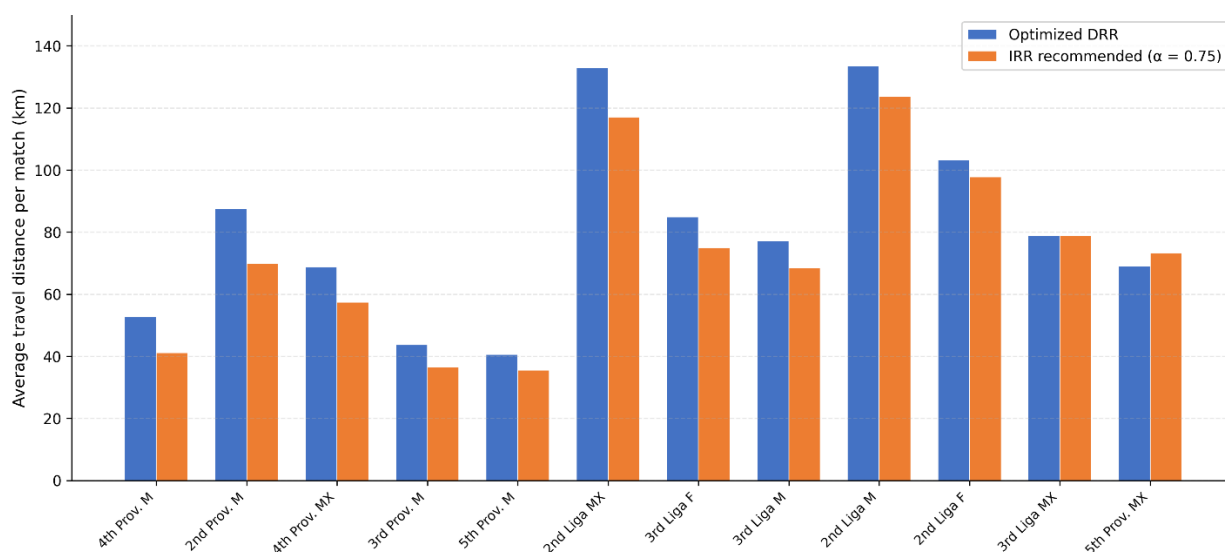


Figure 6: Average travel distance per match for each division, optimized DRR vs. IRR recommended

The structural advantage of the IRR format is illustrated by Figures 7 and 8, which compare the DRR group structure and the IRR matchup pattern for the 3rd Liga Women's division. This division contains 24 teams drawn from across Flanders, organized into four DRR groups. The number of away matches is identical in both formats (120), so the 11.6% improvement in average distance per away match (from 84.9 km to 75.0 km) is entirely attributable to the opponent selection flexibility that the IRR format provides.

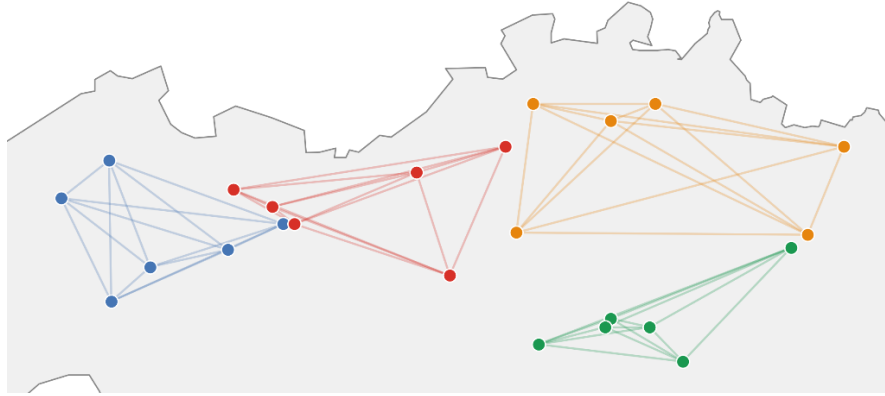


Figure 7: DRR groups for the 3rd Liga Women's division

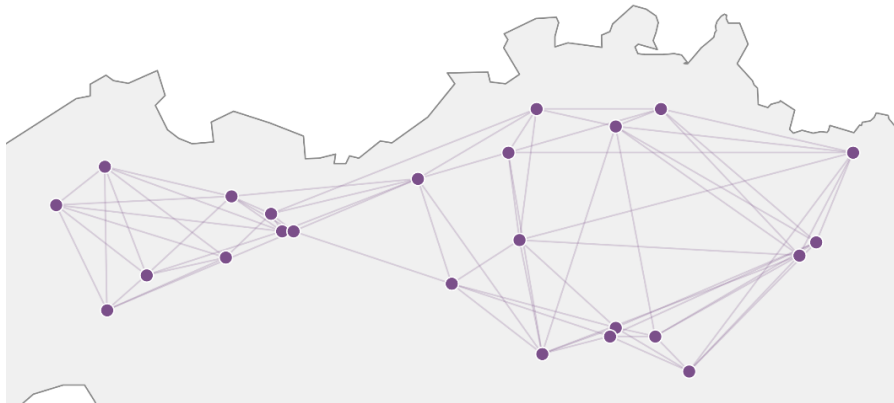


Figure 8: IRR matchups for the 3rd Liga Women's division

Team-level analysis: Table 25 summarizes the team-level results for the recommended IRR configuration, expressed in terms of the average distance per away match. As with the grouping optimization of Section 5.1, sum minimization does not guarantee that every individual team benefits: some teams are worse off because the solver prioritizes aggregate distance reduction. A similar equity extension to that of Devriesere and Goossens (2025) for field hockey, which traces a Pareto frontier between aggregate efficiency and individual equity, could be applied to the badminton IRR formulation but falls outside the scope of this thesis.

Outcome	Teams	Share (%)	Avg. change per away match (km)
Better (IRR < DRR)	143	64.7	-16.9
Worse (IRR > DRR)	51	23.1	+11.8
Unchanged	27	12.2	0
Total	221	100	-8.2

Table 25: Team-level average distance per away match, IRR recommended vs. optimized DRR

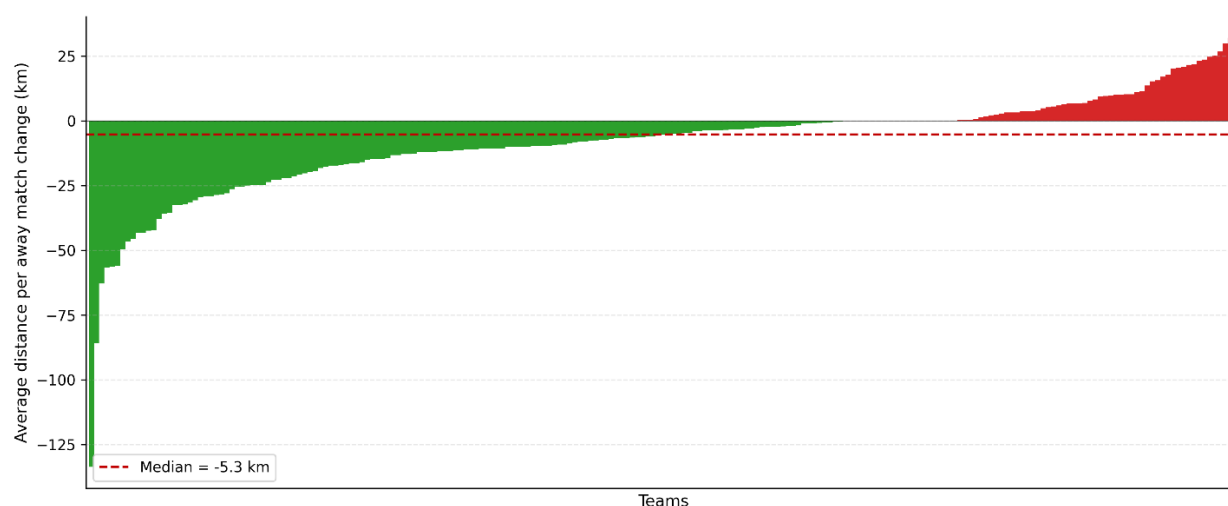


Figure 9: Change in average distance per away match per team, sorted from largest improvement to largest deterioration (IRR recommended minus optimized DRR)

Figure 9 shows the individual change in average distance per away match for each of the 221 teams, sorted from the largest improvement to the largest deterioration. The distribution is negatively skewed, with a median of -5.3 km per away match: the largest individual improvement reaches -133.7 km per away match, while the largest deterioration is +32.0 km per away match. The asymmetry reflects the format's ability to deliver substantial savings for teams that were previously assigned to geographically unfavorable DRR groups, while the cost imposed on disadvantaged teams is comparatively modest.

Maximum individual travel distance: Table 26 reports the maximum average distance per away match within each division under the two formats. In nine of the twelve divisions, the worst-case team travels a shorter average distance per away match under IRR, with reductions up to 99.0 km per away match in the 2nd Liga Mixed Competition. The effect of intra-club separation on worst-case distances, which is particularly pronounced in divisions containing clubs with multiple entries, is examined in detail in Section 5.3.4. Three divisions show a modest increase, the largest being the 5th Provincial Mixed, discussed in the division-level analysis above.

Division	DRR max avg/away (km)	IRR max avg/away (km)	Change (km)
2nd Prov. M	131.2	92.0	-39.2
3rd Prov. M	78.8	73.7	-5.1
4th Prov. M	103.7	58.0	-45.7
4th Prov. MX	128.7	96.7	-32.0
5th Prov. M	56.4	56.7	+0.3
5th Prov. MX	125.5	149.2	+23.7
2nd Liga W	184.0	122.8	-61.2
2nd Liga M	185.7	157.0	-28.7
2nd Liga MX	252.7	153.7	-99.0
3rd Liga W	142.0	117.2	-24.8
3rd Liga M	144.3	154.7	+10.3
3rd Liga MX	163.3	158.7	-4.7

Table 26: Maximum average distance per away match per division

5.3.4 Multi-Entry Clubs Under the IRR Format

As discussed in Section 5.1.3, the DRR club-separation constraint imposes a structural travel penalty on multi-entry clubs by forcing at least one team into a geographically distant group. Under IRR, the intra-club encounter ban (Constraint IRR-1) replaces this separation constraint, allowing both teams of a multi-entry club to draw opponents from the full divisional pool.

Across the 12 multi-group divisions, 14 clubs enter multiple teams in the same division, yielding 38 teams from multi-entry clubs in total. Table 27 summarizes the effect of the format change on this subset.

Metric	Value
Teams from multi-entry clubs	38 (14 clubs, 19 club-division pairs)
Better (IRR < DRR)	31 (81.6%)
Worse (IRR > DRR)	4 (10.5%)
Unchanged	3 (7.9%)
Avg. change per away match	–21.9 km
Avg. within-club disparity, DRR	41.3 km
Avg. within-club disparity, IRR	5.5 km

Table 27: Summary statistics for teams from multi-entry clubs, optimized DRR vs. IRR recommended ($\alpha = 0.75$)

Of the 38 teams, 31 (81.6%) experience a reduction in average distance per away match under IRR, compared to 64.7% among all 221 teams in multi-group divisions (Table 25). The average improvement of 21.9 km per away match likewise exceeds the division-wide average of 8.2 km, confirming that the IRR format disproportionately benefits teams that are structurally disadvantaged under DRR. The most revealing metric is the within-club disparity, defined as the difference in average distance per away match between the two teams of a club in the same division. The average disparity drops from 41.3 km under DRR to 5.5 km under IRR, indicating that the format change not only reduces travel distances but distributes them more equally across club members.

Table 28 illustrates this equalization for the 3rd Liga Men's division, continuing the analysis of Table 14 in Section 5.1.3. This division contains the two clubs with multiple entries that served as the motivating example for the club-separation penalty: Dijlevallei (teams 3H and 4H) and De Mintons (teams 1H and 2H).

Club	Team	DRR avg/away (km)	IRR avg/away (km)	Change (km)
De Mintons	1H	87.0	78.0	–9.0
	2H	118.0	68.0	–50.0
Within-pair gap		<i>31.0</i>	<i>10.0</i>	<i>–21.0</i>
Dijlevallei	3H	52.3	43.0	–9.3
	4H	128.7	43.0	–85.7
Within-pair gap		<i>76.4</i>	<i>0.0</i>	<i>–76.4</i>

Table 28: Average distance per away match for multi-entry club teams in the 3rd Liga Men's division, optimized DRR vs. IRR recommended ($\alpha = 0.75$)

As Table 28 shows, IRR eliminates the within-pair gap for Dijlevallei entirely and narrows it for De Minton from 31.0 to 10.0 km. In both pairs the previously more burdened team improves the most.

The four multi-entry club teams that experience an increase under IRR are in each case the clubmate that benefited from a favorable group assignment under DRR. In all four cases, the net effect for the club as a whole is positive: the previously disadvantaged team gains substantially more than the previously advantaged team gives up.

The case with the largest individual improvement across all multi-entry clubs is Looise in the 2nd Liga Mixed Competition, illustrated by Figures 10 and 11. This division is one of two in which the grouping optimization of Section 5.1 achieved no improvement at all (Table 11), because no regrouping could reduce the total divisional distance. The club-separation constraint forced Looise 2G into a distant group, resulting in an average of 252.7 km per away match, while Looise 1G averaged 119.0 km, a within-pair gap of 133.7 km. This made Looise 2G the team with the highest individual travel distance across all teams in all divisions, a position that the grouping optimization was unable to improve. Under IRR, both Looise teams average 119.0 km per away match, a reduction of 133.7 km for Looise 2G and a complete elimination of the within-pair disparity. The number of away matches remains six for both teams in both formats, so the improvement is entirely attributable to the opponent selection flexibility of the IRR model.

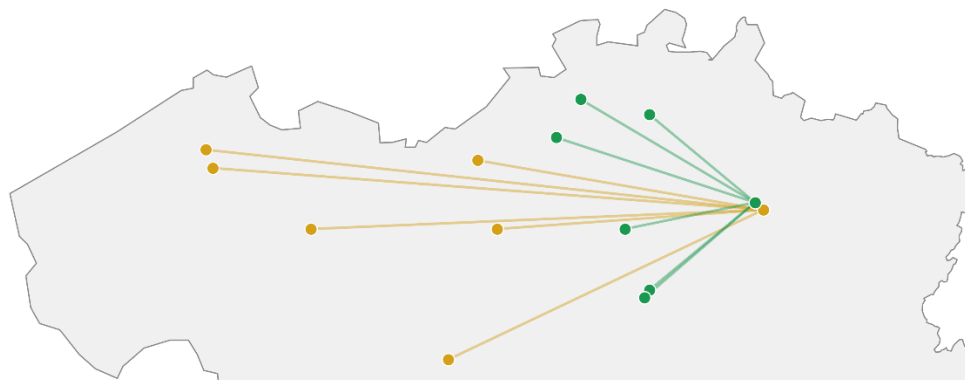


Figure 10: Looise 1G (green) and Looise 2G (yellow) away matches in the optimized DRR groups



Figure 11: Looise 1G (green) and Looise 2G (yellow) away matches in the IRR format

Together with the results of Sections 5.3.2 and 5.3.3, the findings of this section confirm that the IRR format consistently improves upon the DRR baseline in terms of travel distance while largely eliminating the structural penalty on multi-entry clubs. The broader implications of these results, including the trade-off between travel distance and competitive fairness, are discussed in Chapter 6.

6. Conclusion

6.1 Summary

This thesis addressed three interrelated problems in the planning of interclub competitions for Badminton Vlaanderen: the team grouping problem, the match scheduling problem, and the evaluation of an Incomplete Round Robin format as a structural alternative to the current competition design. Each problem was formulated as an integer programming model and solved using CPLEX.

The team grouping problem concerned the assignment of teams within each division to competition groups such that total travel distance is minimized. The integer programming formulation of Section 4.1 reduced total travel distance across the twelve multi-group divisions by 11,996 km (11.1%), from 108,180 km to 96,184 km. The magnitude of improvement differed between competition levels, consistent with the grouping practices described in Section 3.1.4: the VVBBC provincial divisions accounted for 82.5% of the total savings with a 25.6% reduction, while the Liga divisions yielded a 3.0% reduction. Beyond the direct distance savings, the optimized grouping serves as a controlled baseline for the comparison with the IRR format, ensuring that any reported improvement under IRR is attributable to the format change itself rather than to suboptimal grouping quality.

The scheduling model produced feasible multi-league schedules satisfying all organizational constraints while optimizing two independent quality dimensions: unwanted matches and triple breaks. The objective function alone sufficed to eliminate all unwanted matches, while the bucket constraint framework of Section 4.2.2 reduced triple breaks from 374 (unconstrained baseline) to 189 in the best-performing configuration, R15. Both metrics improve upon the BV reference schedule (199 triple breaks, 16 unwanted matches), and all feasible configurations solved to proven optimality within 600 seconds, confirming that the model remains tractable at operational scale.

The IRR extension demonstrated that replacing fixed group boundaries with free opponent selection can meaningfully reduce total travel distance while preserving competitive fairness. At the recommended configuration ($\alpha = 0.75$), total travel distance across the twelve IRR-eligible divisions falls 9.1% below the optimized DRR baseline, with the strength balance constraint tightening the maximum relative dispersion from 2.306 to 0.746 at a marginal travel cost of 3.6% above the unconstrained optimum. The format proved disproportionately beneficial for clubs entering multiple teams in the same division: the average within-club disparity in average distance per away match fell from 41.3 km under DRR to 5.5 km under IRR, largely eliminating the structural penalty that the group-separation constraint imposes under the current format.

The travel distance reductions achieved by the grouping optimization and the IRR extension carry implications beyond operational efficiency. Lower travel distances translate directly into reduced travel costs for clubs and players, who in amateur competitions typically bear their own expenses, and into time savings for participants. The cumulative reduction of nearly 21,000 km in total round-trip driving distance (comparing the original grouping to the recommended IRR configuration) also contributes to lower carbon emissions across the competition season.

6.2 Limitations and Future Research

Several limitations of this work should be acknowledged, each suggesting directions for further investigation.

The grouping optimization of Section 4.1 minimizes travel distance as a single objective, without consideration of cross-group strength balance. As shown in Section 5.3.2, the optimized grouping exhibits a higher maximum strength dispersion across divisions than the original grouping: the geographically compact groups happen to produce a less balanced distribution of team strengths. This limitation is particularly relevant for the comparison between DRR and IRR in Section 5.3.2, where the DRR reference points on the Pareto front reflect a grouping optimized for travel distance only, while the IRR formulation explicitly incorporates opponent strength balance constraints. The comparison of competitive balance outcomes therefore reflects both the structural differences between the formats and the asymmetry in optimization objectives. A more methodologically rigorous comparison between the two formats would integrate opponent selection, scheduling, and strength balance constraints in a single model for the DRR format, analogous to the IRR formulation of Section 4.3 but retaining the fixed group partition. Under such a formulation, the DRR solver would jointly determine which teams serve as opponents within each group and assign timeslots, subject to the same strength balance constraints applied to the IRR model. Li and Goossens (2025) demonstrate the feasibility of integrating grouping and scheduling decisions in multi-league settings, extending this approach to incorporate strength balance constraints would constitute the most direct methodological equivalent of the IRR formulation developed in this thesis, and represents a natural direction for future research.

The bucket constraint framework and triple break analysis are not applied to the IRR extension. The IRR analysis is restricted to two quality dimensions (travel distance and opponent strength dispersion), and adding a third would require testing a large number of configurations combining bucket constraint families, rolling window variants, and strength balance parameter values. This extension would reduce rather than enhance the analytical clarity of the comparison. The effectiveness of the bucket constraints has been demonstrated for the DRR format in Section 5.2, and the exclusion from the IRR analysis is a

deliberate scope restriction rather than a modelling limitation of the IRR formulation. A relevant direction for future research is to investigate whether the bucket constraint families developed in this thesis transfer effectively to the IRR setting. Recent work has begun to address break minimization in Incomplete Round Robin tournaments in compact scheduling settings (de Werra et al., 2025), but the time-relaxed variant, where idle weeks complicate the relationship between bucket constraints and breaks as demonstrated in Section 5.2.1, has been studied less extensively.

The three-phase decomposition schedules DRR and TRR groups before IRR groups. Because the DRR/TRR phase has no travel distance objective, its variable fixings are arbitrary among the set of feasible schedules and may consume venue capacity that the IRR solver would otherwise have exploited for better matchups. Reversing the phase order to schedule IRR groups first would grant them unrestricted access to venue capacity under the travel distance objective and would have been a better choice.

The computational resources allocated to the IRR model impose limits on solution quality at tight strength balance values. For $\alpha = 0.4$, the Phase 2A MIP gap at termination is 48.36%, meaning that the reported travel distance of 140,936 km is an upper bound and the true optimum at this α level may be lower. For the minimum- α solution, the MIP gap of 100% indicates that a tighter α than the reported 0.355 may be achievable with additional computation time. The relax-and-fix and fix-and-optimize heuristics developed by Van Bulck and Goossens (2021) for time-relaxed sports timetabling could improve these bounds.

Finally, the scheduling model is implemented using IBM ILOG CPLEX Optimization Studio. The free Community Edition of CPLEX restricts problem sizes to 1,000 variables and 1,000 constraints, far below the scale of the models in this thesis. Operational adoption of the models by Badminton Vlaanderen would therefore require access to a full CPLEX license or migration to an alternative solver. The models and code are otherwise designed for reuse: with adaptation of the input files (JSON data, configuration file, and tournament Excel file), the same formulations can be applied to schedule future seasons.

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Appendix A: Triple Round Robin Constraint Formulation

This appendix presents the complete constraint formulation for the one group in the BV competition operating under a Triple Round Robin (TRR) format: Limburg Men's third division, comprising four teams. In the TRR format, each pair of teams meets exactly three times across the season. The scheduling requirements underlying these constraints are described in Section 3.1.2, their role within the broader model is discussed in Section 4.2.1.

All notation follows that of Section 4.2.1. The set G^{TRR} contains only this single group.

Triple Round Robin Constraints

$$\sum_{s \in S_g} (x_{i,j,s} + x_{j,i,s}) = 3 \quad \forall g \in G^{TRR}, \forall i, j \in T_g, i \neq j \quad (10)$$

$$\sum_{s \in S_{g,f}} (x_{i,j,s} + x_{j,i,s}) \leq 2 \quad \forall g \in G^{TRR}, \forall i, j \in T_g, i \neq j \quad (11)$$

$$\sum_{s \in S_{g,r}} (x_{i,j,s} + x_{j,i,s}) \leq 2 \quad \forall g \in G^{TRR}, \forall i, j \in T_g, i \neq j \quad (12)$$

$$\sum_{s \in H_i} x_{i,j,s} \leq 2 \quad \forall g \in G^{TRR}, \forall i, j \in T_g, i \neq j \quad (13)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_i} x_{i,j,s} - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_j} x_{j,i,s} \leq 1 \quad \forall g \in G^{TRR}, \forall i \in T_g \quad (14)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_j} x_{j,i,s} - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in H_i} x_{i,j,s} \leq 1 \quad \forall g \in G^{TRR}, \forall i \in T_g \quad (15)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g,f}} (x_{i,j,s} + x_{j,i,s}) - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g,r}} (x_{i,j,s} + x_{j,i,s}) \leq 1 \quad \forall g \in G^{TRR}, \forall i \in T_g \quad (16)$$

$$\sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g,r}} (x_{i,j,s} + x_{j,i,s}) - \sum_{\substack{j \in T_{g(i)} \\ j \neq i}} \sum_{s \in S_{g,f}} (x_{i,j,s} + x_{j,i,s}) \leq 1 \quad \forall g \in G^{TRR}, \forall i \in T_g \quad (17)$$

Constraint (10) requires that each ordered pair of distinct teams within the TRR group meets exactly three times over the full season, one more than under the Double Round Robin format. Constraints (11) and (12) distribute these three encounters across both halves of the season by capping each pair to at most two meetings per half, ensuring that no pair plays all three matches within a single round. Constraint (13) bounds the number of times a team may host the same opponent to at most two.

Constraints (14) and (15) enforce global home/away balance over the full season for TRR groups. Under the Double Round Robin format, season-level balance is guaranteed structurally by constraint (1): because each ordered pair plays exactly one home encounter, every team automatically plays the same number of home and away matches across the season. Under the Triple Round Robin format, this structural guarantee no longer holds. Constraint (10) requires three encounters per pair without specifying their direction, and constraint (13) permits a team to host any given opponent at most twice. Within the space defined by constraints (10) and (13) alone, it is therefore possible for a team to host every opponent twice and visit each once. Constraints (14) and (15) address this by bounding the difference between total home and total away matches per team across the full season to at most one.

Constraints (16) and (17) enforce distributional balance across the two rounds: the difference in total matches played by any team between the first and return round may not exceed one, preventing an uneven number of matches across the two halves of the season. Together, constraints (14)–(17) ensure that both the directional balance and the temporal distribution of matches remain fair across all teams in the group.