

THE APPLICATION OF OPTIMISATION TECHNIQUES IN CRICKET: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Operations research represents a scientific procedure that offers a quantitative motive for problem-solving and decision-making by characterising functional relationships as intricate mathematical models. Intuitively, the benefits presented by optimisation theory as a subset of operations research denote a testament to its involvement with distinct industries, including sports such as cricket. Cricket is a global phenomenon that polarises purpose by adopting a quasi-religious significance for selected audiences. This study aims to investigate existing literature involving optimisation applications in cricket team selection and batting order sequencing by conducting a systematic literature review. Accordingly, this study reveals prospective research opportunities by recognising fundamental shortcomings in existing literature. Therefore, this study contributes to academia and industry by identifying the potential research gap involving decision-making of player selection and ordering using optimisation theory. While this investigation primarily considers optimisation procedures within cricket, it is recommended that future studies pursue parallel research for alternative sports.

Keywords: batting order, cricket, optimisation, systematic literature review, team selection

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1 INTRODUCTION

Modern decision-making has become increasingly complex due to constantly changing social, technological, and intellectual factors [1]. The persistent changes brought about by the Fourth Industrial Revolution exert additional pressure on adjudicators to exercise the correct choices under varying conditions [2]. Consequently, decision-makers can no longer depend on personal intuition and experience alone to draw reliable conclusions [1]. Therefore, utilising scientific methods such as operations research to sustain decision-making proves invaluable as it offers superior solutions based on quantitative evidence [1].

Operations research comprises numerous components, including optimisation theory, of which mathematical optimisation forms a subset concerned with finding the best solution subject to some constraints [3]. Accordingly, mathematical optimisation seeks an optimal solution from a set of alternatives using models describing the functional relationships among entities [1]. The decision-making capabilities introduced by this domain sustain its involvement in various global industries, such as logistics [4], [5], finances [6], [7], politics [8], [9], healthcare [10], [11], and sports [12], [13], [14]. Many sports regularly utilise different optimisation techniques for improved decision-making, with cricket being one of the most prominent [15].

Cricket, one of the oldest sports globally, experienced somewhat of a cultural transformation over the prior two decades with the introduction of its shortest format [16]. Traditionally, the sport enjoys an elite status owing to its rich history spanning multiple centuries [17]. However, modern-day cricket has since become a multi-billion-dollar business industry, with substantial revenue accumulated through player, coach, and team performances [18]. This transformation produces smaller margins among international and domestic teams, signifying the importance of adequate decision-making as a competitive means [19]. Accordingly, utilising mathematical optimisation to derive conclusions is essential as it enhances the scientific nature of decision-making using quantitative evidence void of prejudice and bias [1].

As with any team sport, player selection and positioning dictate success [20]. Therefore, the best players must be selected to maximise general team performance. Cricket is distinct in that participants perform differently under varying internal and external phenomena. Match conditions significantly influence cricketing performance, providing that selectors may opt to include players having more adaptability than their counterparts. Additionally, players fulfil particular roles within the side, underpinning the significance of team selection in obtaining a balanced squad accommodating all playing abilities. However, although player selection is crucial for success, the corresponding arrangement of the chosen side is equally important as cricketers embody dissimilar strengths and weaknesses. Therefore, employing mathematical optimisation techniques for team selection and batting order optimisation proves essential for maintaining an uncontested advantage in an ever-changing sport such as cricket [21].

Swartz [22] discusses different research directions involving cricket, including team selection and batting order optimisation. The study [22] mentions the lack of quantitative research within the sport, signifying a need for further work concerning analytical methods. Therefore, the current study aims to investigate existing literature involving optimisation applications in cricket team selection and batting order sequencing by conducting a systematic literature review. To accomplish this aim, the study identifies the following objectives:

- to provide a concise overview of cricket and mathematical optimisation;
- to determine the number of studies that use optimisation techniques for cricket team selection and batting order optimisation;
- to identify which optimisation techniques are applied for cricket team selection and batting order optimisation;
- to investigate the predominant playing formats considered by existing literature; and
- to provide valuable recommendations for prospective research.

This study reveals the optimisation techniques considered by existing literature, consequently exposing those yet to be explored. Theoretically, this study contributes by offering prominent research opportunities recognised by the gap in existing literature disclosed by the limitations of the resultant findings. Practically, this study contributes by revealing the methods available for empirical player selection and ordering. Accordingly, the current work contributes to both academia and industry, demonstrating the value of utilising analytical techniques to optimise cricket team selection for best performance.

The paper is outlined such that each succeeding passage logically complements the preceding content. Following the introduction in Section 1, Section 2 presents a traditional literature review that provides insight into cricket and mathematical optimisation. Thereon, Section 3 describes the systematic literature review method and protocol, followed by a discussion of the consequent research results. Finally, Section 4 concludes the study by summarising the content, accompanied by applicable limitations and recommendations for future work.

2 LITERATURE REVIEW

Section 2 provides a concise overview of cricket and mathematical optimisation, signifying the background needed to comprehend the essence of the study.

2.1 Origin of cricket

The sport of cricket polarises purpose by assuming a quasi-religious significance for some and a mere form of entertainment for others [23]. Cricket, often hailed as the gentleman's game [24], is the second most popular sport on the planet, with approximately 2.5 billion supporters [22], [25]. In its simplest form, cricket denotes a game played using a single bat and ball [23]. Modern sources credit the English for the invention of cricket, although the exact origin of the sport is somewhat unknown [23], [24]. Malcolm [23] claims that the sport contains Celtic roots, first played by the Scottish and Irish, approximately 500 Anno Domini. Contrarily, Groombridge [26] and Pradhan *et al.* [27] discuss its potential origin in France, with Mote [28] mentioning the likely ancestry of cricket in Iceland and Flanders. However, regardless of the widespread speculation regarding the origin of cricket, the earliest unambiguous reference to the sport as an entity was made in 1597 [27].

2.2 Gameplay and laws of cricket

Cricket is an intricate game played between two teams, each containing eleven members with one substitution [29]. The game is played on an annular field encompassing a central 20-meter strip, called the pitch [30]. The pitch confines a wicket on each opposing side, comprising two horizontal bails balanced on three stumps [30]. Surrounding the wicket on each side of the pitch is a crease, demarcated by white lines, specifying the legal play for both teams [31]. Additionally, the circular field encompasses a 27-meter inner circle, measured from the centre of each wicket [32]. The inner circle contains two semicircles of radius 27 meters surrounding the width of the pitch, converged by two parallel lines [32].

The objective of cricket is to maximise the number of runs achieved such that it is more than the total scored by the opposing team [30]. A coin toss, performed between the captains of each side before the initiation of the game dictates which team bats or bowls first [33]. The bowling team uses all eleven players to restrict the number of runs accumulated by the batting side [34]. Alternatively, the batting team uses two batsmen to score runs, with the relationship between these players known as a partnership [35]. The purpose of each individual batsman is to accumulate runs while simultaneously defending their wicket [36]. Players score runs by striking the ball and running to the opposite end of the pitch before any fielder dislodges the bails of the wickets [37]. Likewise, players obtain runs by striking the ball beyond the boundary of the field [37]. Further, teams gain runs, known as extras, from law infringements committed by the bowling side [29]. Figure 1 shows a cricket ground depicting the discussed phenomena.

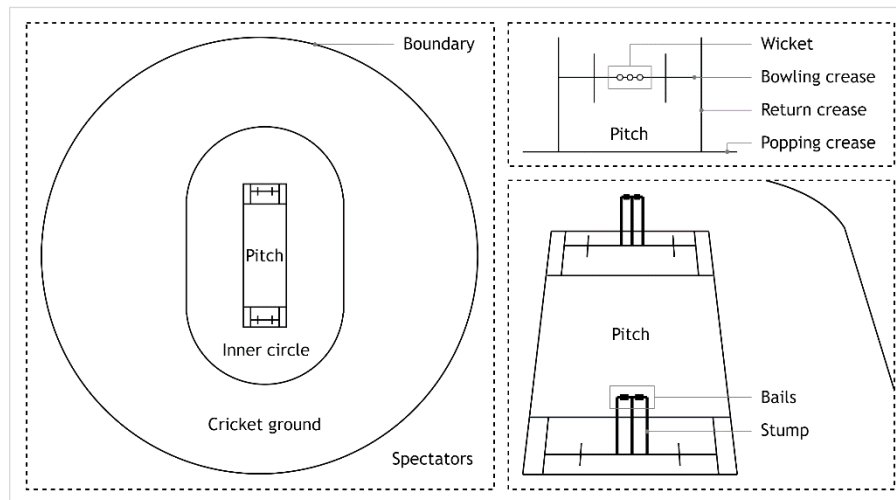


Figure 1: Cricket ground [32]

The period in which a particular team bats is called an innings [29]. The duration of an innings depends on the number of predefined overs as stipulated by the match format [33], [36]. An over comprises six legal deliveries [33], which involves propelling the cricket ball along the length of the pitch toward the wicket guarded by the batsman. Intuitively, the purpose of the bowling team is to minimise the runs accumulated by the batting team [30]. Accordingly, the bowling team can restrict the number of runs scored by terminating the batting innings of the opposing side either through the accumulation of ten wickets or the completion of the defined number of overs [29], [34]. The bowling team accumulates wickets by dismissing the batsmen of the opposing team [29]. Once the bowling side has dismissed a cricketer, the player deemed out is replaced by the subsequent batsman in the specified lineup [38]. After a particular side has completed their batting innings, the opposing team receives an opportunity to bat [34]. Consequently, the team that scored the most runs after both teams completed their batting innings is deemed the winner of the match [39].

2.3 Formats of cricket

At an international level, cricket comprises three official formats, classified based on limited and unlimited overs [40]. Unlimited overs cricket, also known as test cricket, refers to games played without an upper bound placed on the number of overs per innings [41]. Test cricket represents the earliest form of the game, played over five days, with each side having two independent opportunities to bat [33]. Alternatively, limited overs cricket involves formats containing a predefined number of balls, allowing play to conclude in a single day [33]. Limited overs cricket takes the form of One Day Internationals (ODIs) and Twenty20s (T20s) [42]. ODIs generally encompass a minimum span of eight hours [43], with each team having 50 overs to bat [33]. T20s represent the shortest international format, taking approximately three to four hours to complete, with each team allowed 20 overs to bat [43]. Since its introduction, interest in limited overs cricket, especially T20s, has grown significantly globally [44].

2.4 Overview of mathematical optimisation

Operations research is a scientific method for decision-making that uses mathematical models to describe functional relationships among entities [1]. Operations research denotes a broad field comprising various techniques, of which mathematical optimisation is perhaps the most significant [45]. Sinha [45] defines mathematical optimisation as a decision-making approach concerning the adequate utilisation of finite resources to accomplish some desired objective. Accordingly, mathematical optimisation seeks an optimal solution by deriving the best result among multiple alternatives subject to several constraints [1]. Williams [46] mentions the importance of mathematical optimisation models by signifying their proficiency in revealing

underlying relationships between entities that would otherwise not be apparent. Sharma [1] provides the subsequent provisions for formulating a mathematical optimisation model:

- Decision variables: Represent controllable factors whose values are obtained by solving the defined problem.
- Objective function: Denotes the criteria employed for evaluating alternatives based on different decision variable values to optimise performance.
- Constraints: Refer to the policies and regulations limiting the use of selected resources, expressed as inequalities or equations.

Mathematical optimisation encompasses two classifications, including discrete and continuous [47]. Discrete optimisation requires variables that form part of a discrete set [48]. Conversely, continuous optimisation permits a continuous range of values for the model parameters [1]. Further, mathematical optimisation problems can adopt a constrained or unconstrained nature [1]. Constrained optimisation problems impose fixed limitations on their corresponding values that mandate adherence without exception [1]. Alternatively, in unconstrained optimisation problems, restrictions on the use of finite resources are not inflicted [1]. Finally, optimisation problems are considered deterministic or stochastic [49]. Deterministic models are those in which the parameters and functional relationships are known with certainty [1]. Alternatively, if the model contains at least one random variable, the problem is said to be stochastic [1]. Stochastic models provide a more realistic representation of practical occurrences since they accommodate the unpredictability involved in selective phenomena [49].

2.5 Classification of optimisation techniques

Multiple sources provide dissimilar views on the classification and terminology of optimisation techniques [50], [51], [52]. Accordingly, the joint classification provided by Ayalew *et al.* [53], Russenschuck [3], Subramanyam *et al.* [54], Khodr *et al.* [55], and Sharma [1] are considered in this study. Ayalew *et al.* [53] classify optimisation techniques into three categories, namely traditional methods, artificial intelligent, and hybrid artificial intelligent approaches. Among these three categories, Ayalew *et al.* [53] specify procedures such as linear programming, nonlinear programming, integer programming, simulated annealing, genetic algorithms, and fuzzy logic. Likewise, Russenschuck [3] offers a detailed overview of techniques concerning numerical procedures, such as dynamic programming and network flow theory. Subsequently, Subramanyam *et al.* [54] and Khodr *et al.* [55] view data envelopment analysis as a distinct optimisation technique, with Sharma [1] offering a descriptive handbook comprising various additional methods, such as Markov chains and goal programming.

2.6 Mathematical optimisation techniques

Section 2.6 describes the different optimisation techniques applicable to this study, furnishing the background necessary to comprehend the results of the succeeding review.

2.6.1 Linear and integer programming

Linear programming denotes the foundation of combinatorial optimisation [56], first proposed by Dantzig in 1947 as a means for solving complex logistics problems [1]. Linear programming is a deterministic method that optimises some linear function subject to a finite set of linear constraints [1]. Accordingly, in linear programming, the amount of each resource employed is proportionate to the value concerning each related decision variable [1]. However, in 1958, Gomory extended prior work conducted by Dantzig, Johnson, and Fulkerson by applying cutting planes that ensure an integer solution, leading to the creation of integer programming [57].

Integer programming problems are those in which at least one variable adopts a nonfractional discrete state [58]. Integer programming problems are deemed pure, mixed, or binary based on the provisions of the model constraints [58]. An integer programming problem is said to be

pure if all decision variables are integer-valued [1]. Conversely, a mixed integer programming problem limits some, but not all, of the decision variables to integer quantities [1]. A binary integer programming problem provides a set of constraints that restricts the decision variables to either zero or one [1]. Equations (1), (2), and (3) offer the compact formulation of a binary integer programming problem having n decision variables and m constraints [1]:

$$\text{Minimise } Z = \sum_{j=1}^n c_j x_j \quad (1)$$

$$\text{Subject to } \sum_{j=1}^n a_{ij} x_j \geq b_i, \text{ for } i = 1, 2, \dots, m \quad (2)$$

$$x_j = 0 \text{ or } 1, \text{ for } j = 1, 2, \dots, n \quad (3)$$

From the compact formulation, c_j represents the cost coefficient associated with the decision variable x_j [1]. Similarly, a_{ij} denotes the constraint coefficient and b_i the related constraint requirement, with the decision variable x_j bounded to either 0 or 1 [1].

2.6.2 Goal programming

Goal programming denotes an approach used for solving multi-objective optimisation problems by finding a satisfactory trade-off among numerous conflicting and incommensurable goals at different priorities [1]. Goal programming was first mentioned in 1955 [59] but only explicitly introduced by Charnes and Cooper in 1961 [1]. This approach satisfies the model goals in an ordinal sequence and aims to achieve a satisfactory level for each goal rather than an optimal result [1]. Accordingly, this method analyses the exact, over, and underachievement of goals by integrating deviational variables that monitor the degree to which the target performance values are not achieved [60]. Deviational variables are two-dimensional since they provide the negative and positive divergence from each model goal and sub-goal, denoting the equivalent of slack variables employed in linear programming [59]. The deviational variables that permit underachievement or overachievement of the target value for the i th goal is expressed as [1]:

- d_i^- = underachievement of the target value (negative deviation).
- d_i^+ = overachievement of the target value (positive deviation).

The standard formulation of a goal programming model assumes a similar notation as used for linear programming [1]. However, in goal programming, the deviations from the target values relating to the model goals are minimised by placing the relevant deviational variables directly in the objective function [60]. Equations (4), (5), and (6) provide the standard formulation of a goal programming problem combining preemptive priorities and weighting [60].

$$\text{Minimise } Z = \sum_{i=1}^m \sum_{k=1}^{n_i} P_i (w_{ik}^- d_i^- + w_{ik}^+ d_i^+) \quad (4)$$

$$\text{Subject to } \sum_{j=1}^n a_{ij} x_j + d_i^- - d_i^+ = b_i, \text{ for } i = 1, 2, \dots, m \quad (5)$$

$$x_j, d_i^-, d_i^+ \geq 0, \text{ for } i = 1, 2, \dots, m; \text{ for } j = 1, 2, \dots, n \quad (6)$$

From the preceding formulation, the objective function Z denotes the minimisation of the sum of deviations from the target values associated with the model goals [60]. The coefficients w_{ik}^- and w_{ik}^+ signify the non-negative weights assigned to each of the $k = 1, 2, \dots, n_i$ subgoals within the i th goal comprising the preemptive priority factor P_i [60]. The P_i parameter specifies the priority level allocated to each goal, with a_{ij} the constants pertaining to each variable x_j [1].

2.6.3 Simulated annealing

Simulated annealing is a popular meta-heuristic introduced in 1983 by Kirkpatrick, Gelatt, and Vecchi [61] for solving complex black-box optimisation problems [62]. The method is based on an analogy to thermodynamics in which materials are heated and cooled until some final state is achieved [61]. Simulated annealing iteratively compares the values of the present solution to those pertaining to the newly selected solution [63]. Improving solutions are accepted, with the related temperature parameter offering the likelihood of accepting inferior solutions [63].

2.6.4 Genetic algorithm

Holland introduced the genetic algorithm in 1975 as a nature-inspired approach following the theory of evolution proposed by Darwin [64]. Genetic algorithms contain three phases, namely crossover, mutation, and fitness selection [65]. The algorithm starts with an initial population containing various individuals with related chromosomes [64]. Next, a fitness function is used to determine the goodness of each solution, with parent chromosomes subsequently selected to produce offspring using crossover and mutation [64]. The offspring then replace the current individuals of the population following an analysis of their related fitness [64].

2.6.5 Data envelopment analysis

Data envelopment analysis is a linear programming approach, first defined in 1978 by Charnes, Cooper, and Rhoades [66]. The aim of data envelopment analysis is to determine the efficiency of different decision-making units in converting inputs into outputs [66]. This approach allows simultaneous consideration of numerous inputs and outputs without any assumptions on the distribution of the data [66]. The efficiency of each unit is acquired based on the proportionate change in inputs and outputs, with the entities compared using an efficiency frontier [66].

2.6.6 Dynamic programming

Bellman first introduced dynamic programming in the 1950's [67] as a technique for analysing sequential decision processes [68]. Dynamic programming involves dividing a complex problem into multiple subproblems and using the subproblem solutions to find a general solution to the complete problem [69]. Accordingly, dynamic programming structures optimisation problems into numerous stages, each sequentially solved to obtain a final solution [1].

2.6.7 Fuzzy logic

Fuzzy logic, founded in 1965 by Zadeh, aims to mimic practical decision-making by considering imprecise and vague values instead of binary true or false statements [70]. Therefore, fuzzy logic deals with subjectivity, ultimately providing a better representation of reality by bridging language and human intelligence [71]. Fuzzy logic allocates degrees of membership to entities using the unit interval zero and one, where real numbers on this interval denote partial truths ranging from absolute false to absolute true [72].

2.6.8 Markov chain

In 1905, Markov developed the Markov chain, which is a probabilistic model that describes the sequence of system events, with the likelihood of each event realising depending only on the preceding state [1]. Markov chains model the behaviour of a system over time, enabling future

state prediction using a finite matrix of transition probabilities [1]. The matrix of transition probabilities encompasses the conditional probabilities of being in some future state given the attainment of some current state [1]. Markov chain analysis assumes that the system starts in some initial state, with all states mutually exclusive and collectively exhaustive [1].

3 SYSTEMATIC LITERATURE REVIEW

Section 3 introduces the method and protocol used to investigate existing literature, with the resultant findings subsequently discussed and the opportunities for future work conveyed.

3.1 Research method and research results

Modern research mandates synthesising information from a seemingly infinite supply so as to ensure that only relevant material is considered [73]. There are various research methods for synthesising knowledge [73], with systematic reviews being one of the most prominent [74]. A systematic review assumes a methodological nature as it evaluates all existing literature on a particular research question [75]. The power of such a review predominantly lies in its ability to better the general foundation of knowledge concerning a specific subject [76].

The study presents a systematic literature review with a protocol adapted from the guidelines proposed by Kitchenham *et al.* [75] and Kitchenham [77]. The protocol comprises six dissimilar stages, including research question conceptualisation, search process, inclusion and exclusion criteria, quality assessment, data collection, and data analysis. Figure 2 outlines the selected protocol, depicting the systematic nature of the discussed procedure.

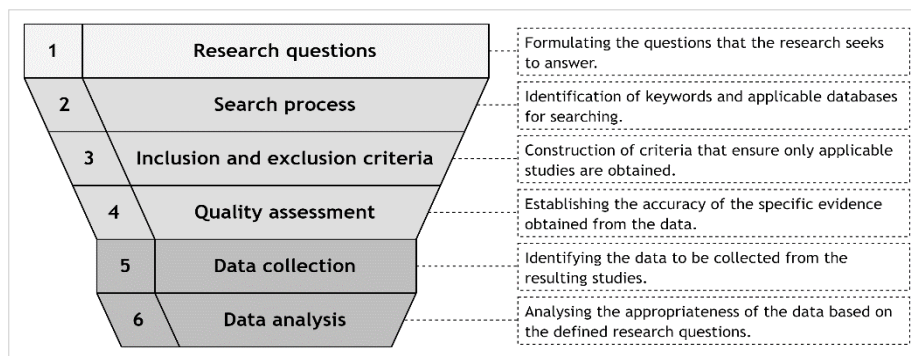


Figure 2: Research protocol stages [75], [77]

Figure 3 demonstrates the application of the research protocol depicted in Figure 2. Foremost, three research questions are identified, which guide the course of the study by outlining the particular focus of the review. Next, the search process involves selecting suitable keywords and databases for extracting evidence from existing literature. Accordingly, two keyword sets are formulated, with five prominent databases used to identify the studies, including Scopus, ScienceDirect, Web of Science, IEEE Xplore, and EBSCOhost. Thereon, inclusion and exclusion criteria, with a quality assessment method adapted from the guidelines proposed by Mangaroo-Pillay and Coetzee [78] and Bisset *et al.* [79], are used to confirm the accuracy and sufficiency of the research results. Finally, data collection and analysis transpire, ensuring the adequate answering of the initially defined research questions.

The quality assessment method yielded 26 distinct research results, shown by the information outlined in Figure 3. However, the authors of these papers frequently referred to alternative studies exhibiting a dissimilar combination of the defined keyword sets. A manual analysis was used to determine the relevancy of these studies by inspecting the titles and abstracts of the referenced work. The manual analysis revealed 10 additional studies, introducing a combined aggregate of 36 distinct findings. Table 1 summarises the original 26 research results, whereas Table 2 provides the supplementary 10 studies. The numbering convention in Table 2 continues from Table 1 so as to ease the cross-referencing of studies in subsequent content.

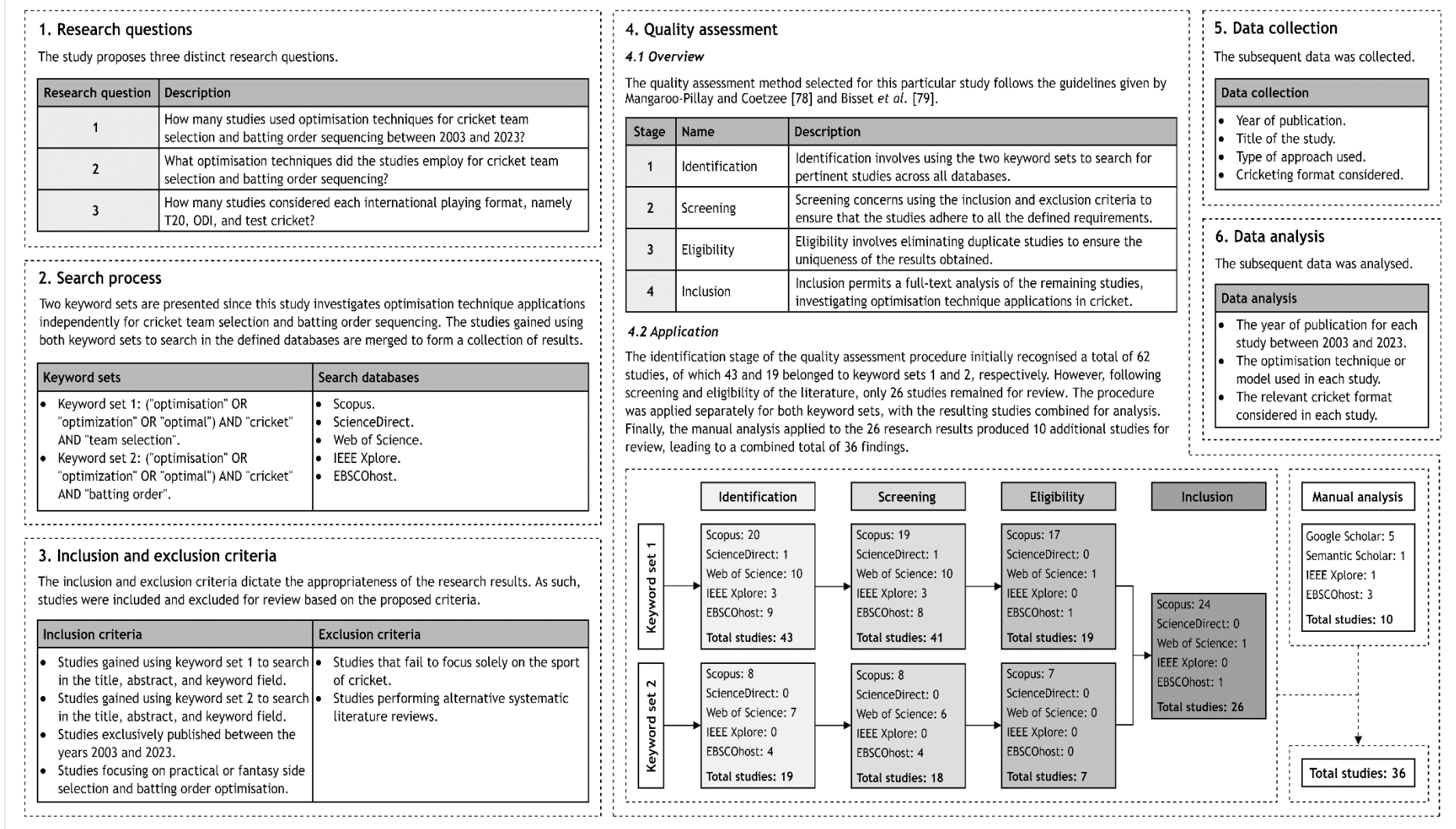


Figure 3: Research protocol application

Table 1: Final research results of quality assessment

No.	Year	Title	Approach	Format	Reference
1	2023	Optimization of team selection in fantasy cricket: a hybrid approach using recursive feature elimination and genetic algorithm.	Random forest recursive feature elimination and genetic algorithm.	ODI	Jha <i>et al.</i> [80].
2	2022	A balanced squad for Indian Premier League using modified NSGA-II.	Genetic algorithm.	T20	Verma <i>et al.</i> [81].
3	2021	Predicting optimal cricket team using data analysis.	Subjective weighting system.	T20	Jadav <i>et al.</i> [82].
4	2020	Extraction of strong and weak regions of cricket batsman through text-commentary analysis.	Text-based mining using a regular expression matching algorithm.	T20	Rauf <i>et al.</i> [83].
5	2020	Machine learning-based selection of optimal sports team based on the players performance.	Machine learning using a random forest algorithm.	ODI	Shetty <i>et al.</i> [84].
6	2020	Best'11 strategy in cricket using MCDM, rough matrix and assignment model.	Multi-criteria decision making, rough matrices, and integer programming.	ODI	Vijayabalaji & Balaji [85].
7	2020	An innovative super-efficiency data envelopment analysis, semi-variance, and Shannon-entropy-based methodology for player selection: evidence from cricket.	Data envelopment analysis, semi-variance, and Shannon entropy.	ODI	Adhikari <i>et al.</i> [86].
8	2019	Decision making in cricket: the optimum team selection.	Integer programming.	T20	Saikia <i>et al.</i> [87].
9	2019	A sequential principal component-based algorithm for optimal lineup and batting order selection in one day international cricket for Bangladesh.	Sequential principal component analysis.	ODI	Shanto & Awan [88].
10	2018	Team selection using multi-/many-objective optimization with integer linear programming.	Integer programming.	T20	Chand <i>et al.</i> [89].
11	2016	A new model for player selection in cricket.	Composite indices.	T20	Saikia <i>et al.</i> [34].
12	2016	Optimal lineups in Twenty20 cricket.	Relative value statistics and simulated annealing.	T20	Perera <i>et al.</i> [90].
13	2016	An objective approach of balanced cricket team selection using binary integer programming method.	Integer programming.	T20	Bhattacharjee & Saikia [91].
14	2014	On performance measurement of cricketers and selecting an optimum balanced team.	Integer programming.	T20	Bhattacharjee & Saikia [92].
15	2013	Team selection after a short cricket series.	Integer programming.	ODI	Lemmer [93].
16	2013	Multi-objective optimization and decision making approaches to cricket team selection.	Genetic algorithm.	T20	Ahmed <i>et al.</i> [94].
17	2013	Selecting the optimum cricket team after a tournament.	Integer programming.	T20	Bhattacharjee & Saikia [95].

No.	Year	Title	Approach	Format	Reference
18	2012	A multi-stage integer programming approach to fantasy team selection: a Twenty20 cricket study.	Integer programming.	T20	Brettenny <i>et al.</i> [96].
19	2011	Cricket team selection using evolutionary multi-objective optimization.	Genetic algorithm.	T20	Ahmed <i>et al.</i> [21].
20	2011	Integer optimisation for the selection of a Twenty20 cricket team.	Integer programming.	T20	Sharp <i>et al.</i> [97].
21	2010	Optimal batting orders in cricket.	Dynamic programming.	All	Norman & Clarke [98].
22	2009	Applying genetic algorithm to select an optimal cricket team.	Genetic algorithm.	ODI	Sathya & Jamal [99].
23	2007	Dynamic programming in cricket: optimizing batting order for a sticky wicket.	Dynamic programming.	Test	Norman & Clarke [100].
24	2006	A mathematical modelling approach to one-day cricket batting orders.	Markov chain.	ODI	Ovens & Bukiet [101].
25	2006	Optimal batting orders in one-day cricket.	Simulated annealing.	ODI	Swartz <i>et al.</i> [37].
26	2003	Dynamic programming in cricket: choosing a night watchman.	Dynamic programming.	Test	Clarke & Norman [102].

Table 2: Final research results of manual analysis

No.	Year	Title	Approach	Format	Reference
27	2019	A DEA model for selection of Indian cricket team players.	Data envelopment analysis.	Test	Chaudhary <i>et al.</i> [103].
28	2017	Optimal one day international cricket team selection by genetic algorithm.	Genetic algorithm.	ODI	Kumarasiri & Perera [40].
29	2014	Moneyballer: an integer optimization framework for fantasy cricket league selection and substitution.	Integer programming.	T20	Das [104].
30	2014	Cricket team selection using data envelopment analysis.	Data envelopment analysis.	T20	Amin & Sharma [105].
31	2011	Selection of cricket players using analytical hierarchy process.	Fuzzy analytic hierarchy process.	N/A	Kamble <i>et al.</i> [106].
32	2010	Integer optimisation for the selection of a fantasy league cricket team.	Integer programming.	T20	Brettenny [107].
33	2009	Integer optimization for the selection of a Twenty20 cricket team.	Integer programming.	T20	Lourens [108].
34	2006	Selecting a limited overs cricket squad using an integer programming model.	Integer programming.	ODI	Gerber & Sharp [109].
35	2004	A criterion for comparing and selecting batsmen in limited overs cricket.	Two-dimensional framework.	ODI	Barr & Kantor [110].
36	2003	Cricket team selection using genetic algorithm.	Genetic algorithm.	ODI	Omkar & Verma [111].

3.2 Discussion of research results

Section 3.2 discusses the different research results by answering the initially defined research questions, offering valuable insight into probable opportunities for prospective work.

3.2.1 Research question 1: How many studies used optimisation techniques for cricket team selection and batting order sequencing between 2003 and 2023?

Figure 4 presents a bar chart exhibiting the distribution of the combined 36 findings based on the year of publication. Figure 4 demonstrates that most of the work involving cricket player selection and sequencing was executed between 2009 and 2014, with a corresponding total of 14 publications. Further, Figure 4 indicates that 2020 contains the most publications on this topic, showing an aggregate of 4 unique studies.

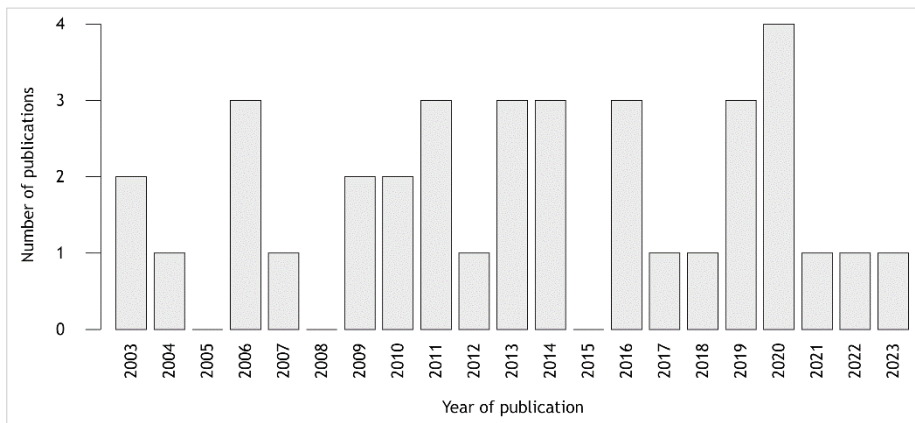


Figure 4: Number of studies published between 2003 and 2023

Although the keyword sets formulated in Figure 3 specifically limit the scope of the review to mathematical optimisation, many of the resultant studies employ alternative approaches, such as statistical methods. However, the focus of this study involves deterministic and stochastic optimisation techniques with the consideration of heuristics and solution-based methods. Therefore, considering the approaches followed by the research results, the study consults existing literature to ensure an accurate classification of the employed techniques. Figure 5 presents the number of studies that utilised optimisation techniques, classified using the framework introduced in Section 2.5. Figure 6 shows the applicability of the databases by demonstrating the number of studies given by each source. The subsequent illustrations offer valuable insight into the adequacy of the review by illustrating the relationships between the distinct study approaches and sources.

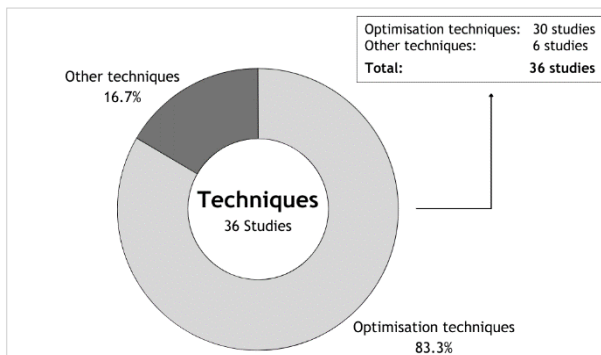


Figure 5: Studies per technique

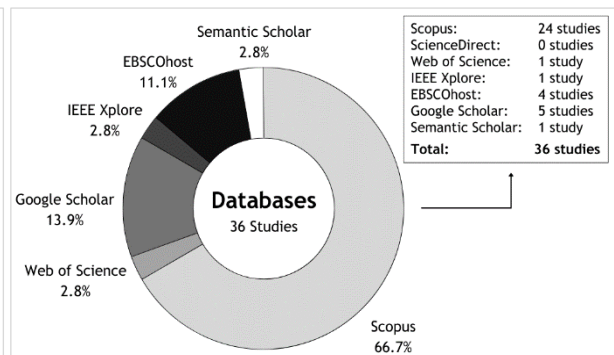


Figure 6: Studies per database

Numerous studies combined multiple approaches, such as statistical models and optimisation algorithms. Therefore, all studies that used optimisation techniques for problem formulation

or solving were classified as such. Hence, Figure 5 reveals that, between 2003 and 2023, 30 studies used optimisation techniques for cricket team selection and batting order sequencing. Figure 6 encompasses databases not initially defined as part of the search process, associated with the supplementary studies obtained from the manual analysis. Figure 6 shows that Scopus accounts for 66.7% of the results, offering insight for future studies pursuing parallel work.

3.2.2 Research question 2: What optimisation techniques did the studies employ for cricket team selection and batting order sequencing?

The preceding subsection shows that 30 studies used optimisation techniques, such as integer programming, simulated annealing, genetic algorithms, data envelopment analysis, dynamic programming, fuzzy logic, and Markov chains. Figure 7 offers a bar chart depicting the number of studies considering each optimisation technique, recalling the classification in Section 2.5.

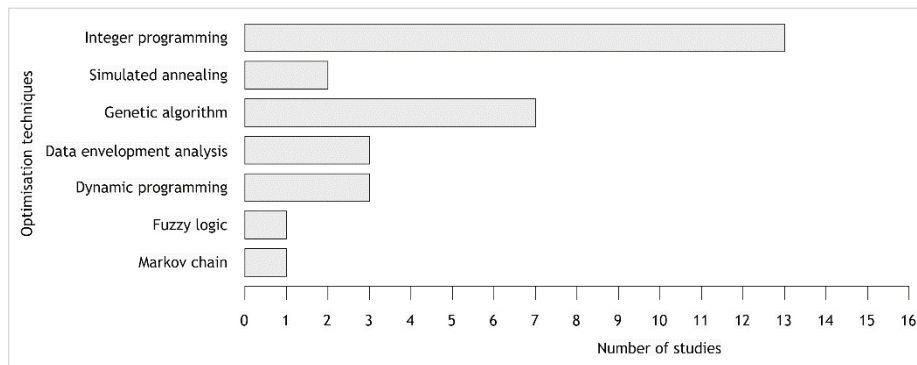


Figure 7: Number of studies per optimisation technique

As discussed, various studies utilise numerous techniques for team selection and batting order optimisation. Therefore, considering Figure 7, the studies were classified based on the specific procedures employed to select and sequence cricketers. As such, 13 and 3 studies conducted player selection and ordering using integer and dynamic programming, respectively. Similarly, 2, 7, and 1 papers used simulated annealing, genetic algorithms, and fuzzy logic, respectively. Finally, 3 studies applied data envelopment analysis, whereas only 1 considered a Markov chain approach. Table 3 lists the studies associated with each optimisation technique in Figure 7.

Table 3: Studies associated with each optimisation technique

Technique	Name	Study	Total
1	Integer programming	6, 8, 10, 13, 14, 15, 17, 18, 20, 29, 32, 33, 34	13
2	Simulated annealing	12, 25	2
3	Genetic algorithm	1, 2, 16, 19, 22, 28, 36	7
4	Data envelopment analysis	7, 27, 30	3
5	Dynamic programming	21, 23, 26	3
6	Fuzzy logic	31	1
7	Markov chain	24	1

3.2.3 Research question 3: How many studies considered each international playing format, namely T20, ODI, and test cricket?

Recall from Section 2.3 that cricket, at an international level, comprises three official formats viz. T20, ODI, and test. However, certain studies provide models with necessary adjustments so as to ensure their applicability in all playing formats. Accordingly, in such cases, the match form used to test the model is considered the applicable playing format. From Table 1, Study 21 involves all playing formats as it provides two unique models for optimising batting lineups in limited and unlimited overs cricket. Further, Study 31 does not consider a particular format

and instead offers a general method for player ordering. However, team selection and batting order optimisation significantly depend on the playing format. Therefore, Table 2 shows that the suggested formats are not applicable (N/A) to Study 31 owing to its generic model. Figure 8 presents the number of studies associated with each format, considering Study 21 separately for T20, ODI, and test cricket. However, Figure 8 excludes Study 31 as its proposed procedure does not specifically consider any of the three mentioned game structures.

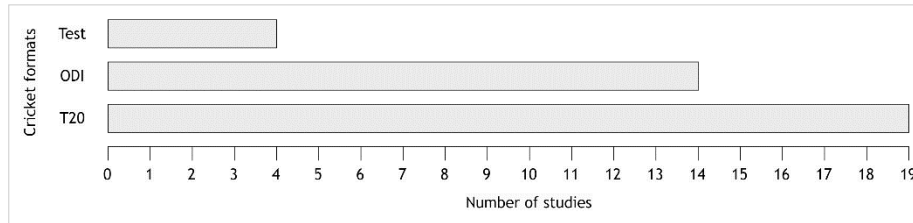


Figure 8: Number of studies per cricket format

Figure 8 illustrates that 4, 14, and 19 studies perform either team selection or batting order optimisation for test, ODI, and T20 cricket, respectively. Accordingly, most research on team selection and batting order optimisation predominantly focuses on limited overs cricket, with minor consideration of the test playing format.

3.3 Research opportunities

The results from the systematic review indicate numerous opportunities involving cricket team selection using mathematical optimisation techniques. The findings reveal that current team selection methods in existing literature provide limited flexibility concerning the treatment of multiple objectives and constraints [106]. Accordingly, these procedures fail to permit any deviation from the preconceived target values subject to achievement. Further, Chand *et al.* [89] mention the conflicting nature of cricketing abilities formulated as objectives. Therefore, future research can consider using a goal programming approach to find an acceptable team that balances the trade-off between these conflicting and incommensurable playing abilities. The recommended approach in goal programming introduces more flexibility in team selection by accommodating the contrasting nature between the different abilities through deviational variables that allow marginal divergence from the presumed target values. Assembling a team using goal programming will better reflect the practical environment as it depicts the dynamic nature of selection rather than simply finding the best players to form an optimal side.

Further, the review shows various studies considered team selection in T20 leagues, focusing on the IPL. However, most of these papers select the playing eleven rather than the universal squad of tournament-based cricketers obtained from the player auction. Accordingly, many of these studies perform team selection from the baseline, neglecting fundamental auctioning rules and regulations, including player retention, budgetary constraints, mandatory Indian players, and franchise exchanges. Also, these studies fail to distinguish between the IPL mini and mega-auction, each of which presents different provisions for player selection owing to dissimilar retention rules. Swartz [22] sustains these findings by mentioning that prior research has not yet investigated the IPL auction in detail, recommending player selection within this domain as potential work for prospective research. Accordingly, future research can extend the existing work by offering a unique mathematical model that enables cricket team selection specifically within the dynamic player auctioning process.

Recall from the preceding subsection that only 4 studies considered team selection and batting order optimisation within test cricket. Accordingly, a significant opportunity exists for future research to model batting lineups in test cricket, with each team having multiple opportunities to bat under different scenarios containing distinct uncertainties. Future studies can consider employing stochastic programming with resource, which utilises corrective action to combat undesirable results [112]. Stochastic programming with resource involves postponing decisions

to future stages after experience obtained from initial findings has removed some or all of the underlying uncertainties [112]. Therefore, future studies can utilise this approach to maximise the number of runs achieved by optimising the batting lineup for the second innings using the experience gathered and the uncertainties observed during the first innings.

4 CONCLUSION, LIMITATIONS, AND RECOMMENDATIONS

Section 4 summarises the study by recalling the core details associated with each preceding passage, followed by the related limitations and recommendations.

4.1 Study summary

Mathematical optimisation, as a subset of operations research, contains multiple applications, with cricket being no exception. Cricket is a complex bat-and-ball game played by 22 members across various formats. Success in cricket significantly relies on player selection and ordering owing to its multidisciplinary nature [94]. Therefore, utilising quantitative methods to attain optimality involving squad composition and player sequencing becomes essential. Accordingly, this study provides a unique systematic literature review investigating optimisation technique applications in cricket team selection and batting order optimisation.

The systematic literature review conducted in this study follows a research protocol based on the guidelines specified by Kitchenham *et al.* [75] and Kitchenham [77]. The protocol yielded 26 distinct research results, comprising studies concerning cricket team selection and batting order optimisation. However, the authors of these consequent studies frequently referred to alternative papers having a dissimilar combination of the defined keyword sets. Accordingly, these supplementary studies were included for review following a manual analysis, producing a combined total of 36 distinct research results.

The 36 research results were discussed and evaluated, signifying their corresponding methods, playing formats, and application areas. The analysis showed that 30 studies used optimisation techniques, such as integer programming, dynamic programming, simulated annealing, Markov chains, fuzzy logic, genetic algorithms, and data envelopment analysis. Further, the review showed that limited overs cricket has received the most attention, with significant prospects yet to be explored for test cricket. Accordingly, the study offers a comprehensive framework for future research by revealing the considerations and related limitations concerning existing research, signifying its holistic contribution to academia and industry.

4.2 Limitations and recommendations

The study comprises selected limitations and recommendations subsequently summarised:

- The study uses multiple keyword sets to assess optimisation technique applications in cricket team selection and batting order sequencing. As such, it is recommended that future research broaden the search to all sports by eliminating the keyword: cricket. Removing this keyword and excluding all nonathletic studies will offer valuable insights into solving similar player selection and ordering problems in alternative sports.
- The review exploits five prominent research databases: Scopus, ScienceDirect, Web of Science, IEEE Xplore, and EBSCOhost. Therefore, an opportunity exists for future work to extend the current search by including further recognised databases. Considering additional databases may produce supplementary results, furthering insight into team selection and batting order sequencing using mathematical optimisation techniques.
- Cricket is a sophisticated game lacking no shortcomings in statistical data or numerical phenomena. Accordingly, it is recommended that future studies examine optimisation technique applications involving alternative aspects of cricket. Additional applications of optimisation techniques in cricket worth investigating involve forecasting of possible match-fixing within T20 leagues and general score prediction.

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