A Comprehensive Review of Hybrid Game Theory Techniques and Multi-Criteria Decision-Making Methods.

Muhammad Akram Ramadhan Ibrahim[1], Nor Izzati Jaini[2*] and Ku Muhammad Naim Ku Khalif[3]

[1,2,3]Centre of Mathematical Sciences, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia

*ati@ump.edu.my

Abstract. More studies trend to hybrid the game theory technique with the MCDM method to aid real-life problems. This paper provides a comprehensive review of the hybrid game theory technique and MCDM method. The fundamentals of game theory concepts and models are explained to make game theory principles clear to the readers. Moreover, the definitions and models are elaborated and classified to the static game, dynamic game, cooperative game and evolutionary game. Therefore, the hybrid game theory technique and MCDM method are reviewed and numerous applications studied from the past works of literature are highlighted. The main contribution of the recent studies of employment between game theory technique and MCDM method are analyzed and discussed in detail which includes static and dynamic games in the non-cooperative game, cooperative game, both non-cooperative and cooperative games and evolutionary game.

1. Introduction

The theory of games began his study in 1944 with the publication of the book entitled Theory of Games and Economic Behavior [1] which was written by John von Neumann and Oskar Morgenstern. The game theory has been expanded with the publications of Nash's papers [2]–[5] and Shapley [6] which involved both non-cooperative and cooperative games theory. According to Myerson [7] in 1991, game theory is about competition and cooperation using mathematical models among intelligent and rational decision-makers (DMs). Non-cooperative game is a competitive situation where every participant is interacting with each other to improve their payoffs independently [8] and potentially affect interest preferences [9]. Meanwhile, in the context of cooperative game, Neumann and Morgenstern [1] initiated the fundamental concepts of coalitions and Shapley [6] has proposed the well-known single-valued Shapley value solution concept which assigns to each player its expected marginal contribution. Another study has been done in 1954 regarding the power division depends on the majority of types needed to pass a bill called the Shapley-Shubik power index formulated by Lloyd Shapley and Martin Shubik [10].

The competitive environment that includes a participant interaction to other opponent participants to maximize his benefits commonly spreading in human activities. In the last five decades, game theory has been widely used and reviewed in numerous fields and applications such as political science [11]–[13], economics [14], [15], finance [16], [17], water management [18]–[21], supply chain [22], [23], medical and disease [24], [25], timber raw market [26], construction management [27] and selection of the pedagogical method in education [28]. Not only human activities, but game theory can also be used in animals' interaction [29]. It also has increased its use in the social and biological sciences [30].

Also, game theory has been integrated with other methods to improve its drawback in single-dimensional games. Because of the drawback, the game theory seems not to satisfy the players' needs in real situation cases. Therefore, more studies trend to hybrid the game theory with multi-criteria decision-making (MCDM) to cater to this workability problem in real-life situations [31]. Despite the game theory and MCDM combinations being a challenging study area, using the hybrid idea can help to develop more approaches to solve conflict [32].

As the number of hybrid methodologies and models in research work nowadays increases, game theory also has been hybridized with various methods or models to cater the real-life applications. Game theory is one of the operations research studies that has been used progressively in research involving hybrid methods with MCDM, within the same operations research field. Furthermore, the use of hybrid MCDM has been used progressively during the last decade to diverse decision-making methods either among other MCDM methods [33], [34], or within the operations research field. It can handle the confidence level of DMs on the results when adopting a hybrid MCDM with complex and challenging problems.

Also, game theory is one of the combinations that has been made to deal with decision making in various criteria and alternatives in a real-life situation. The theory of games and MCDM must take into account the situations where the players or DMs must include the criteria but it is also related to other DMs' decisions [35]. One advantage in game theory practicing when compared to other decision making techniques is its capability to model the dynamic games where the actions are taken at dissimilar stages, not simultaneously [36]. Meaning that game theory is capable of helping DMs to decide take-turn games. However, the main disadvantage in game theory is the one-dimensional decision that is impractical in real-life applications because it ignores the opponent's behavior in making decisions that have various alternatives to consider while the opponent's behavior affects the performance evaluation of alternatives before making a decision. Thus, a decision-making model by combining game theory and MCDM can be formed effectively [37].

Therefore, this paper will study and analyze the past literature involving both game theory techniques and MCDM methods. This paper aims to provide a comprehensive review of game theory techniques and MCDM methods and highlights the numerous applications studied from previous literature. The main classification of the game theory techniques will be studied and analyzed, which include static and dynamic games in non-cooperative game theory, cooperative game theory and evolutionary game theory.

The remainder of this paper is structured as follows: Section 2 explains the definitions and the models of the game theory generally. Section 3 provides the classifications of game theory techniques. A comprehensive review of the hybrid game theory techniques and MCDM methods prepares in section 4. In section 5, the analysis of the comparison of game theory techniques and MCDM methods are depicted through tables. The future trends of the studies of game theory and MCDM are suggested in section 6. Finally, the sum-up of the review in section 7.

2. Definitions and Models of Game Theory

Game theory comes up with a formal analytical framework with some mathematical instruments to study the complex interactions among rational players [38]. Game theory is one of the mathematical disciplines that is being applied largely by economists. The competition and cooperation among numerous involved parties using the mathematical framework are studied in game theory with the great size of applications consistently being studied [39]. The strategic interaction in a game is a situation where a player takes an action optimally depending on what the opponent players will do. All players are assumed to be rational in game theory. The three basic elements will be as follows:

a. *The player is one of the rational participants who have interests to fight with their opponent players to win a game.*
b. *The strategy is an action which a player selects from a set of possible actions or called a strategy profile.*
c. *The payoff is the utility or outcome each player receives after selecting a strategy from a strategy profile.*

However, concerning these three basic elements in a game, some additional elements can be considered to occur. The additional elements are as follows:

a. *Common knowledge is a situation where all players know that they are assumed as rational players to each other.*
b. *Order of play is discussing when a player should counteract his opponents either simultaneously or sequentially.*
c. *The information set is preparing the player's knowledge about the previous action taken by the opponents.*

The definitions and models of game theory are explained in more detail in the following subsections and subsubsections of this paper.

2.1. Static Game

A static game is a game in which each player makes decisions simultaneously and each player has no knowledge of the decisions made by other players at the same time. It has also been recognized in some literature as a strategic game. The common way to depict this type of game model is a normal-form game. A normal-form game comprises three basic elements which are a set of players, a set of actions and a set of payoff functions for each player. Static games with perfect and imperfect information are explained in subsections 2.1.1 and 2.1.2 respectively.

2.1.1. Static Game with Perfect Information

In a static game with perfect information, the player i does not only know its payoff function but also the opponent players' payoff functions. A static game with perfect information includes:

Definition 1 A static game (or strategic game, or normal-form game or simultaneous-move game) with perfect information is defined as the triplet $\langle N, \{S_i\}_{i\in N}, \{p_i\}_{i\in N} \rangle$:

- A finite set of players $N = \{1, 2, ..., \mathrm{n}\}$,
- A finite or infinite set of strategies S_i for each player $i \in N$,
- Outcomes are strategy profiles (or strategy combinations) set $S = S_1 \times S_2 \times ... \times S_n$ which consist of one and only one strategy from each player i,
- Payoff function (or utility function), $p_i : S \to \mathbb{R}$ for player i 's payoff from strategy profile $S = \{s_1, s_2, ..., s_n\} \in \times_{j=1}^{n} S_j$.

In a static game with perfect information, every player i wants to select a strategy $s_i \in S_i$ to maximize its payoff function $p_i(s_i, s_{-i})$ which depends on the player i 's strategy profile s_i and other players' strategy profiles s_{-i}.

2.1.2. Static Game with Imperfect Information

A static game with imperfect information is also called a Bayesian Game. It is a situation where every player does not have much information about opponent players. Therefore, due to the lack of info, the calculation will involve the expected payoff function in playing a game. To sum, a Bayesian game is defined as follows:

Definition 2 A static game with imperfect information (or Bayesian game) features are

- A set of players N,
- A set of states ε,

and for every player i

- A set of strategies S_i,

- A set of signals T received by every player i at every state ε_i,
- A belief about the states is consistent for every signal τ_i that a player receives,
- A Bernoulli payoff function pairs (s, ε) where s is a strategy profile and ε is a state.

2.2. Dynamic Game

A dynamic game is a situation where the action is taken by one player after the other players or called a sequential move which generally allows the past decisions that have been made can be known by other players. The dynamic game involves a time-based action when a decision is made. One way to represent this dynamic game model is an extensive-form game where a game tree is depicted. Dynamic games with perfect and imperfect information are explained in subsections 2.2.1 and 2.2.2 respectively.

2.2.1. Dynamic Game with Perfect Information

In a dynamic game with perfect information, the player i knows the previous player's action at each terminal. The strategy chosen by the first player is referred to as terminal history that can be fully informed to the next player to make the next move. A set of terminal histories is the set of all sequences of chosen strategies that may happen. A dynamic game with perfect information includes:

Definition 3 A dynamic game (or extensive-form game or sequential-move game) with perfect information is defined as $G = \langle N, H, \mathrm{p}(h), \mathrm{u}_i(h), S(h) \rangle$:

- A finite set of players $N = \{1, 2, ..., \mathrm{n}\}$,
- A set of final history H where the property that no history is a subset of another history,
- A set of histories H,
- A player function $p(h)$ assigns to every non-final history where a player who moves after the subhistory h,
- A payoff function $u_i(h)$ based on each of the final histories which occur,
- A set of strategies for every player $S(h) = \{s_i(h, a)\}$.

2.2.2. Dynamic Game with Imperfect Information

In a dynamic game with imperfect information, the player i does not know the previous player's chosen strategy at that stage. The strategy chosen by the first player may not be perfectly informed to the next player to start a movement. A dynamic game with imperfect information includes:

Definition 4 A dynamic game with imperfect information is defined as $G = \langle N, H, \mathrm{p}(h), \mathrm{I}, \mathrm{u} \rangle$

- A set of players N where the initial player is Nature,
- A set of final history H where the property that no history is a subset of another history,
- A player function $p(h)$ where corresponds to nature and a player which determines each player's turn in a game,
- An information partition I for non-terminal history,
- A probability distribution function for each history which has assigned to Nature over the strategies available at that history,
- A payoff function $u_i(h)$.

2.3. Cooperative Game

A cooperative game is a game in coalition form where the players make a binding agreement to strengthen the relation, in contrast to the non-cooperative game that forms a competition among players to fight with them in a game. A cooperative game is used to divide the worth of cooperation with its player members.

This cooperation form is based on a real-valued function, called the characteristic function of the game [40], [41]. A characteristic function game G is given by a pair (N, v) where N is the set of players and $v: 2^{[2]} \rightarrow \mathbb{R}$ is a characteristic function for a game. The possible cooperation among players that be defined as C and the benefit from the coalition C is $v(C)$ to get the higher payoff when approving to coop together for each C proper subset N in a game.

This means that the worth of the empty coalition is zero and the benefit of all the players, called C grand cooperation, must be the lowest they can get if no cooperation is needed [40]. The possible cooperation will receive added payoffs among all players in this bond. It is at least to make sure that the payoff received by the cooperation is more profitable or defined as superadditivity, rather than act individually on their own.

2.4. Evolutionary Game

Evolutionary game theory is initiated in the context of biological study. It considers a population of DMs and their behavior towards each other. The equilibrium is alike to Nash equilibrium in a strategic game. The evolutionary stable strategies (ESS) was employed by Maynard Smith and Price [42]. An ESS is an equilibrium amelioration of Nash equilibrium.

3. Classifications of Game Theory Techniques

The main classification of game theory techniques is depicted in Fig 1. The following subsections explain the main classifications of the game in this study.

3.1. Simultaneous or Sequential Move

A game with simultaneous and independent movements in which all the players act at the same time without recognizing the movements of other players [40]. Also, the meaning of this simultaneous movement is further expanded that the player chooses an action without being able to observe and interact with other players [43] even if not at the same time. An example of the simultaneous game is the Prisoners' Dilemma where the players are being investigated separately without knowing who takes the action first and cannot communicate at all.

Instead, sequential movements allow the next player to take steps based on the information obtained by observing and interacting with the selection of previous player strategies. Players can take any step after knowing the results of previous players. The meaning of this has been broadened in [43] that what players know before they make a choice. An example of a game is the Battle of the Sexes where a male player makes a decision after a female player. But if the male player decides after a few hours without knowing the strategy that has been chosen by the female player, then this is called a simultaneous move. A Player who chooses strategy with sequential movements but does not have any information is similar to a player who moves simultaneously [40]. Therefore, the important point here is what information the player knows before making a decision, not involving how long it takes after the previous player making a choice.

3.2. Zero-Sum or Non-Zero-Sum Payoff

In general, zero-sum and non-zero-sum games are called constant-sum games regardless of whether the difference of the payoff value is zero or other than zero. However, if the difference of payoff value is zero then it will be called a zero-sum game. The zero-sum game is a situation where the sum of the payoff is zero. This means a condition where one player wins and the other player loses. This game can be transferred as a result of one player to another [44]. The interest between the players is opposite and competitive without the possibility of an agreement among the players. One of the examples of a zero-sum game is matching pennies.

In contrast, a non-zero-sum game is a situation where the sum of the payoff value is not equal to zero. In this game, the players' interests are not always in a conflicting situation because the players are probable to cooperate. So that it occurs in a situation where players gain together. One of the most popular examples is the Prisoners' Dilemma.

3.3. Perfect or Imperfect Information

Perfect information means the player knows every move and payoff of the other players [40]. Each set of information consists of one node [44] or no nature moves [43]. Each player chooses a strategy sequentially and realizes what the other players have chosen. An example of this type of information is the game of chess as each player is exposed to see the movements and strategies on the game board.

Imperfect information means a situation where all players must decide at a certain time without knowing the previous steps taken by the opposing player and the outcome of a random event such as toss a coin [40]. Players also act to ignore the actions of other players instead of expecting it only [44]. Each information set consists of several nodes or the presence of nature moves [43]. An example of this type of information is the card game where each player hides the card they have.

3.4. Non-cooperative or Cooperative Game

In situations that create competition in game theory is called a non-cooperative game, while the state of togetherness between players in a game is called a cooperative game. The behavior of players in a non-cooperative game is more independent because it does not depend on joint decisions between DMs, in contrast to the cooperative game that requires a mutually binding agreement that allows all players to at least the same amount or increase their payoffs when acting individually in a cooperative game. Nash equilibrium solution concepts will be used in finding solutions for the non-cooperative game while in a cooperative game, among the popular solutions used is Shapley value solution concepts.

The difference between non-cooperative and cooperative game theory is commonly understandable with the possibility of binding agreements among the players involved in a certain game. However, Hans Peters [39] argued that the distinction is informal and not clear yet the workable difference between non-cooperative and cooperative are the modeling techniques themselves. It is because the non-cooperative game has explicit strategies whereas, in a cooperative game, the players and cooperations are classified involving payoffs and the outcomes achieved. To conclude these two understandings between the binding agreement concept or the modeling techniques perspective, the constant-sum game mentions a condition where if there is no complete possibility to cooperate (zero-sum game) then the binding agreement statement is reasonable to be accepted because of the explicit strategies. However, if there is a chance to cooperate (non-zero-sum game) then the modeling techniques are reasonable in this case because the payoff and togetherness in the outcomes can be modeled and reached.

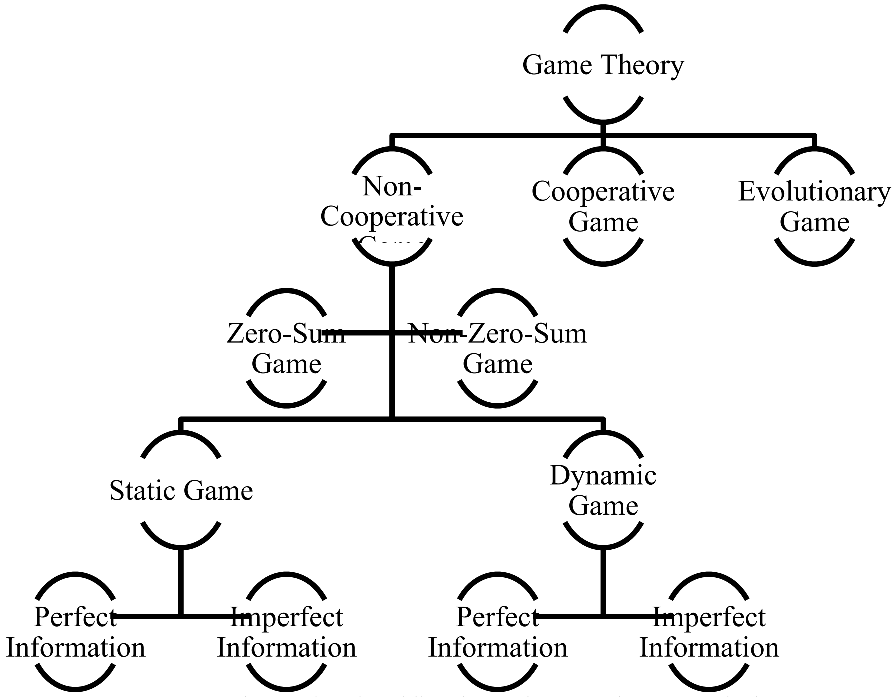

Figure 1. The main classification of game theory techniques.

4. Hybrid Game Theory Techniques and Multi-Criteria Decision-Making Methods

The optimization of the selection problems using the theory of games and MCDM has numerous occasions in research. Each DM has a different goal to achieve and several choices to choose to get an optimal decision at certain selection problem cases.

The following subsections discuss about the hybrid of game theory techniques and MCDM methods that can be found in this study. The following subsections are grouped into subsection 4.1 non-cooperative game, subsection 4.2 cooperative game, subsection 4.3 non-cooperative and cooperative games and lastly subsection 4.4 evolutionary game.

4.1. Non-cooperative Game

In the noncooperative game's subsection, there are three following subsubsections which are 4.1.1, 4.1.2 and 4.1.3 named static game, dynamic game, and both static and dynamic games respectively.

4.1.1. Static Game

Numerous studies have been done involving static games and MCDM. Atashbar et al. [45] proposed a new hybrid approach that involves MCDM methods and game theory framework to study Iran's political economy with three players' normal form game and analyze it from the years 1989 until 2008. The combination of the analytical hierarchy process (AHP) and analytical network process (ANP) into a game theory framework is achieved to make sure its applicability for transforming qualitative to quantitative data for forming payoff matrices using pairwise comparisons. The Nash equilibria were found using the global newton method (GNM). In [46], the combination of game theory techniques and MCDM methods have been used to the personnel selection problems in the human resource management field. The SWARA method was used to evaluate and weigh the strategies, then the game theory part was used for evaluating the appropriate candidate.

Hashemkhani Zolfani et al. [47] proposed a hybrid method to overcome the case where there are more than one Nash equilibria. The MCDM methods used were step-wise weight assessment ratio analysis (SWARA) and weighted aggregated sum product assessment (WASPAS). SWARA is used to evaluate the criteria then weighted it and WASPAS was used to evaluate and select the best Nash equilibrium result from mixed strategies result. The application was used in supply chain management. Rahman et al. [48] proposed research of users' preferences to select the best suitable network in a heterogeneous wireless environment. The proposed methodology of integrated AHP and static game model. AHP was used to evaluate the criteria for dissimilar types of service requests. The result from

AHP then is implemented with strategic game theory to find out optimum network regarding service request particularly using Nash equilibrium.

Liu et al. [49] proposed a new improved methodology of ANP in the MCDM method based on the game theory technique to apply in supplier management with an uncertain case. First, to get the objective and subjective criteria's weights, the ANP and entropy weight (EW) are employed. Second, the step continued with the game theory technique and decision-making trial and evaluation laboratory (DEMATEL) methods to obtain the optimal weight of ANP and entropy weight. Here, the game theory was used to bond both objective and subjective weights meanwhile DEMATEL was used to make a reasonable weight of criteria. To get more comprehensive weights, the Nash equilibrium solution concept was used. Lastly, evidence theory is implemented to deal with uncertain data and get the solution of supplier selection. Khanzadi et al. [50] used the two-person zero-sum game model and the MCDM method. The game theory model has been extended with grey values since the crisp data is problematic that cannot counter the uncertainty and the fuzziness in real-life cases. The DMs' considerations were expressed as grey numbers to tackle the indeterminateness of dispute, opinions and weight of the attributes. The AHP method was used to determine the criteria's weight. Lee [51] proposed the mixed strategy measure of game theory solution concepts with the DEA model. It was first to identify the mixed strategy Nash equilibrium at first stage then considered a probabilistic and multi-oriented efficiency measure at the second stage. The study tests the proposed method with an empirical study of China's electric power industry in 2010. This study focused on the Nash-Cournot game where a game the best outcome for a specific game depends on the outcomes of others.

Nikkhah et al. [52] applied the proposed game theory technique and MCDM methods for solving Mashhad Urban Railway Line 3. The methods used in MCDM were TOPSIS and AHP. The model used in game theory was a two-person zero-sum game. All these methods were used to rank the tunnel risk management groups. Zhu et al. [53] proposed a new framework called stochastic multi-criteria acceptable analysis theory and grey relational analysis (SMAA-GRA) and then the proposed method was applied to two water resources management under uncertain conditions. In this proposed method, the stochastic MCDM problem used the game theory technique to solve the conflict criteria weights based on the Nash equilibrium solution concept. The weight aggregation based on the game theory technique was combined with feasible weight space to estimate the uncertainty.

Ghannadpour & Zandiyeh [54] proposed a new method involved a two-player zero-sum game model and the simple additive weighting (SAW) method in MCDM to implement in vehicle routing problems. Two objective functions were involved to minimize the distance traveled and the risk of cash transfer in vehicle routing problems. The game theory model was used to measure the risk between the cash carrier and the robber. The SAW method was used to predict the robber's probability of success. Chowdhury et al. [55] proposed the integration between the game theory technique and AHP in MCDM and to solve optimum network selection. The proposed methodology was suggested to aid the users in the interface-selection problem in the heterogeneous radio access network environment. The AHP and game theory were used to set up a criteria hierarchy of the evaluation of the network and to obtain the optimum network selection, respectively. Yan et al. [56] improved the TOPSIS method to solve a railway operation safety situation evaluation problem in several regional areas in China from the year 2016 until 2018. The improved TOPSIS method was used to assess the railway operation safety situation towards its indicator. The calculation of the values and rankings of the safety situation, the set-pair analysis theory and cosine similarity measure were used. Then, game theory was employed to show the reason for the combined weight.

Numerous studies have been done involving static games and MCDM with the fuzzy system. Gani [57] introduced the combination of a two-person non-cooperative game Prisoner's Dilemma techniques with TOPSIS in the MCDM method using fuzzy profits. The proposed methodology was used to determine optimal criminals' strategies. Aliahmadi et al. [58] proposed a new methodology based on the game theory technique and fuzzy AHP to evaluate the risk assessment of a tunnel project. Three players involved with cooperative strategies for each player were the highest outcome achieved from the cooperative strategies for the three players.

Bakshi et al. [59] developed a new methodology involving the fuzzy AHP method and static game techniques to aid software project selection. A two-person zero-sum game model was used and the optimal value for both players' strategies was obtained to select the best project and to choose the criteria. However, the result gave the mixed strategies possibility percentage to the projects and criteria without stating which one should be selected uniquely. [60] proposed a novel methodology between ordinal game theory and TOPSIS in MCDM. The proposed methodology was used to find the Nash equilibrium solution concept for choosing the best market supplier with some criteria in a competitive market.

Aplak and Türkbey (Aplak & Türkbey, 2013) presented a hybrid fuzzy TOPSIS in the MCDM method with fuzzy logic and game theory techniques in artificial intelligence. The two-player non-constant sum game model has been considered and both qualitative and quantitative methods were used to join the criteria where the evaluation used fuzzy linguistics then be converted to numbers. The application of an imaginary international disagreement situation is used to check its applicability. Aplak and Sogut (Aplak & Sogut, 2013) proposed a hybrid between game theory techniques with fuzzy TOPSIS in the MCDM method to solve the industrial management decision making process that involved two players which are industry and the environment with conflicting strategies and interests. The optimal strategies using closeness coefficient as a payoff matrix game were found.

Bashir et al. [63] studied the integration between multi-criteria two-players zero-sum game model and intuitionistic fuzzy goals and generalized the study of intuitionistic fuzzy goals with multiple payoff matrices to prove that intuitionistic fuzzy of Pareto-optimal security strategies and security level respectively. Lavanya and Selvakumari [64] introduced a two-person zero-sum game model using the assumption of the triangular, trapezoidal and octagonal fuzzy numbers that are represented as the imprecise values in the payoff matrix. The TOPSIS method has been used to give the optimal strategy to players. The proposed methodology was used by two health insurance companies. Wu et al. [65] introduced a hybrid MCDM method to evaluate the level of sustainability of Chinese coal-fired power units with the involvement of the areal grey relational analysis (AGRA) method in the model also with weighting methods to determine the criteria's priorities. The three combinations were the fuzzy rough set, entropy objective weighting and AHP methods then be evaluated using game theory together. Thirucheran and Kumari [66] introduced a two-person zero-sum game model using dodecagonal fuzzy numbers as imprecise values in the payoff matrix. The fuzzy values were defuzzified to crisp values using ranking methods based on the centroid of centroids methods. Then, the closeness distance strategies for both player one and player two were obtained using the TOPSIS method. The proposed methodology was used to a car selection problem with two manufacturers.

In [67], a two-person non-zero-sum game with a hesitant interval-valued intuitionistic fuzzy-linguistic term set (HIVIFLTS) approach is proposed in the human trafficking problem in society. First is the prisoners' dilemma game that was used under a HIVIFLTS framework and then the problem is solved using TOPSIS and game theory dominance property. Lin et al. [68] developed hybrid MCDM methods which are fuzzy AHP, EW, fuzzy comprehensive evaluation (CE) and fuzzy TOPSIS, and also game theory technique to determine objective and subjective weights for criteria for the evaluation of the comprehensive performance of disc cutters in a tunnel boring machine project. The proposed methodology is implemented as a disc cutter performance evaluation problem. The weights of the criteria were determined using fuzzy AHP, EW and game theory methods. Then, game theory was used to combine objective and subjective weights. Lastly, the evaluation and final ranking of the cutter performance were evaluated using the fuzzy comprehensive evaluation and fuzzy TOPSIS. Zhu et al. [69] proposed a stochastic MCDM based on the stepwise weight information. A new stochastic multi-criteria acceptability analysis (SMAA) theory with a fuzzy optimization model was developed to test its applicability in multi-objective reservoir operation. In this proposed method, the estimation of the uncertainty of criteria weights and multi-stakeholders conflict were solved using a weight aggregation method in game theory. Lau et al. [70] studied the supermarket chain problem in Hong Kong. The proposed study involved a game theory framework with three MCDM methods to get a more optimal solution to the problem that arose. The three hybrid MCDM methods are fuzzy AHP, TOPSIS and the elimination and choice expressing the Reality (ELECTRE). These three methods were used to evaluate the criteria and sub-criteria of supplier performance metrics in positioning the retail outlets to increase the satisfaction of the customers. The mixed strategy model in game theory was used to calculate the monitoring cost of all organic food suppliers.

Some past works of literature involve game theory techniques in the MCDM problem. Madani and Lund [71] put forward MCDM problems as a normal-form game model by using noncooperative game theory solution concepts. An advanced Monte-Carlo Game Theory (MCGT) approach is suggested to deal with the uncertainty of the variable in the performances of the alternatives for solving MCDM problems. The study maps stochastic problems into deterministic strategic games and was solved using non-cooperative game theory solution concepts. The proposed method can be used to conduct MCDM with multi-player problems with uncertainty. The proposed method has been applied to California's Sacramento-San Joaquin Delta problem. Zhou et al. [72] proposed a static game theory in the multi-attribute decision making (MADM) problem to allocate the weight of the attributes to rank and choose the alternatives, and then to make use of the weighted arithmetic average operator to evaluate the attribute values. This proposed method was applied to the problem of purchasing a house.

In [37], the aim was to apply business decision making problems using the game theory technique and MCDM method in a competitive situation. The two-person with two strategies each in a game is considered. The 2-tuple linguistic variable is proposed to represent the DMs' views. Then the two-person game model with linguistic variables is proposed. The application is implemented into a business problem where two companies produce high technology LCD-TV with four criteria for assessing its performance. Yang and Wang [73] introduced a fuzzy matrix game model that can be transformed into a linear programming method to solve a vague linguistic MCDM problem with uncertain weights. The result obtained from the linear programming method is the weights of criteria. These criteria's weights obtained showed the overall evaluation of the alternatives and their ranking.

Deng et al. [74] objectives were to show proof between game theory and MCDM framework in a non-cooperative situation where a player must take into account other players' actions before making a decision. The models used are two-person non-constant sum games and Dempster-Shafer theory[1]. The evaluation of the experts is constituted by belief structures and joined by using the weighing average method. Lastly, the decision is obtained by using the equilibrium of game theory. The application used is a duopoly market game where each company served products and services. In [75], the MADM model was used in the zero-sum game theory model under a fuzzy environment to aid the DM to select the priority of attributes. The game theory part then was transferred into a linear programming problem. The weights of all attributes are based on the strategies' probabilities. The numerical application used is a problem in purchasing a car. Xiao et al. [76] proposed a new multi-objective multidisciplinary design optimization problem based on the Nash equilibrium solution concept in game theory framework and gene expression programming. The proposed model is implemented in the designing of a thin-walled pressure vessel and the hull from the parameter design of a small waterplane area twin hull ship. Thus, the proposed model showed that a better Nash equilibrium was obtained with a more accurate numerical approximation.

Abu-Faty et al. [77] used the TOPSIS method based on the neutrosophic environment to solve Multi-Criteria Group Decision Making (MCGDM) problems by using the closeness coefficient to form the payoff matrix. The methodology used is single-valued neutrosophic sets (SVNs) to constitute the data uncertainty. The TOPSIS method later is used to handle the SVN environment and finally, the two-person non-constant sum game was used to find the optimal solutions. Zandebasiri et al. [78] studied the key players and criteria of Iran's forest crisis in a game framework. The Likert scale was used as the numerical value to total each player's score. The study came out with two Nash equilibria from combined strategies. Qiao et al [79] proposed a game theory technique and characteristics of MCDM methods called the game-theory-extenics model whereas the game theory was used to calculate the cutting performance indexes' weights based on multi-aspect factors that affect the cutting head performance. The proposed methodology was applied to the shield bolter miner in the engineering field in China.

4.1.2. Dynamic Game

Numerous studies have been done involving dynamic games and MCDM. Salehizadeh et al. [80] provided an integrated methodology of a leader-follower game model in game theory and TOPSIS in MCDM method to transmission congestion management in power systems problems. The generation companies' interaction is modeled as the Nash-supply function equilibrium game technique and the TOPSIS method was used to choose the preferred strategy of the operator. Ghorbani Mooselu et al. [81] integrated a new method between the leader-follower game technique and the ELECTRE method to

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[1] A theory of belief functions, where the general framework for thinking with uncertainty that uses probability, also referred to as the theory of evidence.

treat wastewater optimal allocation problem in the eastern part of Tehran, Iran. In the game model, the department of water and sewage was used as the leader and four treated wastewater districts were used as the followers and the model was solved using multi-objective optimization. The best compromise solution was to solve using the ELECTRE model. However, in [31], the study implemented the dynamic game technique to MCDM problem instead of using the common method to hybrid. It proposed an effective methodology involving multi-DM game problems using the linguistic variables to express DMs opinions regarding each criterion for each alternative. The technique in dynamic games used was the backward induction to find the solution of strategies involved. A new linguistic sequential multi-person multi-criteria game is introduced to deal with the production of technology in a competitive market problem.

Besides MCDM, the MADM term has been used in [36]. A Stackelberg model in game theory and evidential reasoning (ER) were used in the MADM method where the consideration of quantitative and qualitative attributes are combined with the uncertainties in calculating alternatives. The leader-follower game, backward induction and Monte-Carlo[2] methods were used to calculate the deterministic and stochastic forms. The proposed method was applied to the largest saltwater lake in the Middle East known as Urmia Lake. The study's capability can be conducted with lots of players at each stage, dissimilar decision-making levels and several uncertainties.

Next, the multi-objective term has been used in [82]. to investigate a multi-objective petroleum supply chain issue using a non-cooperative game model in the first process then completed the steps using mixed-integer linear programming with three objective functions. The game theory solution concept used was the Nash equilibrium and Stackelberg equilibrium. The multi-objective mixed-integer linear programming model was focused on maximizing the profits and job opportunities while minimizing pollution and calculated using a fuzzy programming technique. Lastly, the model was tested on a national Iranian oil company. Xie et al. [83] applied the proposed multi-objective Stackelberg model to optimize the solution of the Chinese arch dam problem or called Baihetan to test the model's practicability and its effectiveness. The model suggested the leader and the follower as preferred targets and other targets respectively. The proposed model advances the multi-objective and the Stackelberg models' similarities from the perspective of the aims, objective functions, design variables and constraints to players, payoff functions, set of strategy and constraints respectively. Latifi et al. [84] proposed a nonlinear interval conflict resolution multi-objective optimization model based on the leader-follower game. The proposed method was used for urban stormwater management. The leader-follower game was used for stakeholders' interactions. The game part produced some Pareto optimal solutions from the players' conflicting utilities. The PROMETHEE model in MCDM was used to choose the most preferred compromised choices.

4.1.3. Static and Dynamic Games

Angelou & Economides [85] proposed a new analysis model that has combined real options, game theory and AHP. The game theory involves both simultaneous and sequential moves in investment. The proposed method has been applied to broadband technology (ICT) business alternatives.

4.2. Cooperative Game

Numerous studies have been done involving cooperative games and MCDM. TOPSIS and cooperative game theory methods are applied in [86] where the TOPSIS is used to the importance of the factor in making a decision to code sharing and merging while cooperative game theory makes a priority ranking of target airlines. Payoffs of market shares are marked and optimal fare rates and daily service frequency is solved using Nash equilibrium. Then the profit distribution is calculated using Shapley values and lastly, TOPSIS is applied to rank the factors that affect the airlines merging and all its coalition choices. Opricović [32] uses the game theory framework to aid the conflict condition and the compromise value using a transferable utility cooperative game. The VIKOR method was calculated to obtain the compromise solution in the MCDM problem. The game theory part explained that criteria are more valuable to measure rather than utilities in the game. It can give a set of efficient compromise solutions instead of one single solution.

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[2] A Monte-Carlo method is a method that uses random numbers to solve a problem [101].

Lv & Zhao [87] used an improved Shapley value solution concept to allocate the profit of the software outsourcing alliances. The AHP method is used to examine the influence factors. The model argued Shapley model ignored dissimilar alliance members' motives despite its ability to avoid average allocation. The study of MCDM and game theory in the cooperative game have been explored by Wei and Zhang [88] proposed the hybrid method between VIKOR in MCDM and Shapley value in cooperative game theory. They used Shapley value solution concepts as a mean value of the marginal contribution of all coalitions with the same position probability. The calculation of the Shapley value was to find the weight of the alone contribution of each criterion. Then they have done a comparative analysis by applying the TOPSIS method to solve the problem based on the Shapley value solution concept. The numerical example to plan the development of large projects by the board of directors of enterprises has been considered.

Hindia et al. [89] suggested a new proposed algorithm of integration cooperative game theory and TOPSIS to improve resource allocation for three smart grid applications. The first step was to calculate the bankruptcy and Shapley value from cooperative game theory to distribute fairly the resources among smart grid applications. Then, the allocation process of the resources to users' applications proceeded for its criteria and preferences. using the TOPSIS method. The findings showed a significant enhancement of the scheduling scheme from other algorithms. Mousavi-Nasab [90] replied to the unfair resources allocation using data envelopment analysis (DEA) and the Nash bargaining solution (NBS) to solve the resource allocation problem based on the overall equipment effectiveness. The DM performance was evaluated using the DEA-NBS model whereas the agreement between DMs' weights contribution in the cooperative game can be achieved efficiently. The Spearman's rank correlation coefficient was used to compare the proposed methods and TOPSIS to determine the equity. The result found that the DEA-NBS method was the fairest and impartial.

Besides MCDM, the MADM term has been used in Tecle et al. [91] cooperative game theory, compromise programming (CP) and the ELECTRE I was used to solving a multi-objective wastewater management problem. Cooperative game theory was used to suggest the most preferred alternative.

Numerous studies have been done involving cooperative games and MCDM with the fuzzy system. Sun et al. [92] combined the merits of fuzzy set theory, game theory and modified evidence combination extended by D numbers to introduce a new decision-making model. The practicability was tested in the evaluation of the health condition of transformers. The assignment of the probability for all indices was obtained using the fuzzy set theory. Then, the subjective weight of indices was done using fuzzy AHP and the objective weight of indices was done using EW respectively. These two calculations were combined to be used in the game theory model as comprehensive weights. Lastly, the modified evidence combination extended by D numbers was suggested to get the final evaluation of the transformers.

Mishra et al. [93] proposed a new hybrid Shapley value solution concept in cooperative game theory and the complex proportional assessment (COPRAS) method in MCDM with hesitant fuzzy information. The new entropy and divergence measures were used to calculate weights of the criteria based on Shapley value solution concepts. The proposed method was tested to service quality decision making then be compared with Shapley TOPSIS for validation of the approach. Rani et al. [94] proposed an extended interval-valued intuitionistic fuzzy VIKOR. To measure the interval-valued intuitionistic sets, the new entropy and similarity measures were used based on the exponential function. The Shapley value solution concept was calculated to cater to incomplete information about the criteria weights. The proposed method was applied to the investment problem.

Jing et al. [95] proposed a fuzzy DEMATEL cooperative game model to perform a relative equilibrium decision approach for concept design in the selection process of the cutting device case study. First, the proposed model used fuzzy DEMATEL to get the objectives' weights. Second, to integrate the weights of the objectives with impact utility into the negotiation theory in the cooperative game model to get the relative equilibrium to fulfill objectives requirements from different strategies. The weighted product method and TOPSIS were used to make a comparative analysis. Mishra & Rani [96] proposed a new methodology that integrated the VIKOR method in MCDM and Shapley value solution concepts in cooperative game theory framework with intuitionistic fuzzy sets. The proposed methodology had been tested for pattern recognition and real cloud service selection problems. Teng et al. [97] developed a modified Shapley value solution concept technique with fuzzy and AHP methods to perform the proposed model. The fuzzy evaluation and AHP were used to evaluate the risk stages of each stakeholder. The fair profit allocation among stakeholders can reduce the risk stage of every stakeholder using the proposed modified Shapley value technique.

Mishra et al. [98] continued the study between Shapley and MCDM methods using Portuguese for Interactive Multicriteria Decision Making (TODIM) with exponential-type divergence measures that applied to fuzzy sets. This proposed methodology was applied to service quality in vehicle insurance firms. The proposed methodology has a unique procedure for the MCDM field.

4.3. Non-cooperative and Cooperative Games

Palafox-Alcantar et al. [99] used the hybrid game theory technique and MCDM to analyze the chance of competitive and cooperative situations. The AHP method was used to calculate the subjective and objective criteria weights for stakeholders. Then, the non-cooperative game theory was used to obtain the most probable outcomes while the Shapley value solution concept in cooperative game theory was used for the allocation method. The test case presented was circular economy waste management in Birmingham, United Kingdom.

4.4. Evolutionary Game

Debnath et al. [100] implemented an evolutionary game theory to multi-agent MCDM in the Indian Tea Industry problem. The probabilities of strategies obtained are constituted as a Dempster-Shafer belief function. A Monte-Carlo simulation and fuzzy stochastic game model are developed to make a decision about the uncertainty of the payoff values and to address the uncertainty of strategic outcomes as well as market fluctuations respectively.

5. Discussion

Many previous works of literature combined game theory techniques with MCDM methods regarding the basic elements of both frameworks. In [31], the DMs evaluate the performance of the strategy of each player. Each strategy has its criteria to take into account. This shows that DM and player are separate identities. The separate identity between DMs and players is also studied in [77] where the DMs evaluation is based on criteria for each strategy. Also, in [47] the criteria are not considered as a strategy. Besides that, in [46] the strategies are evaluated as criteria. However, DMs are also another identity who will select the best solution. The fundamental elements in game theory which are players, strategies and payoffs have similitude with criteria, alternatives and performances in MCDM respectively have been studied in [100]. Hence, these previous studies show that the fundamental elements for both frameworks were studied in various ways.

The integration of game theory techniques and MCDM methods was studied in various applications such as politics, economy, supply chain, engineering, water management problem, allocation problem and telecommunication network selection. Table 1 shows the classification of the studied issues of game theory techniques and MCDM methods with applications. In this study, the static game is mostly used with various MCDM methods in many applications compared to others.

Table 1. Classification of the studied issues between game theory techniques with MCDM methods with some applications.

Game theory model	Application	MCDM method	References
Static game	Politic and economy	AHP ANP	[45]
	Supply chain management	SWARA WASPAS Fuzzy AHP TOPSIS ELECTRE	[47], [70]
	Human resource management	SWARA	[46]
	Railway operation	TOPSIS AHP	[52], [56]
	Vehicle routing problem	SAW	[54]

	Telecommunication network system	AHP	[48], [55]
	Water resource management	SMAA-GRA	[53]
	Supplier selection	ANP EW DEMATEL TOPSIS	[49], [60]
	Prisoners' dilemma	TOPSIS	[57]
	Tunnel project	Fuzzy AHP EW Fuzzy CE Fuzzy TOPSIS	[58], [68]
	Software project selection	Fuzzy AHP	[59]
	International disagreement situation	Fuzzy TOPSIS	[61]
	Industrial management	Fuzzy TOPSIS	[62]
	Engineering	No method	[76], [79]
	Construction project	AHP	[50]
	Electric power industry	DEA	[51]
	Health insurance	TOPSIS	[64]
	Power station	EW AGRA AHP	[65]
	Car selection problem	TOPSIS	[66]
	Human trafficking problem	TOPSIS	[67]
	Reservoir operation	SMAA	[69]
Dynamic game	Transmission congestion management in power system problem	TOPSIS	[80]
	Treated wastewater optimal allocation problem	ELECTRE	[81]
	Production of technology in competitive market problem	No method	[31]
	Saltwater lake	ER	[36]
	Petroleum supply chain problem	No method	[82]
	Urban stormwater management	PROMETHEE	[84]
	Chinese arch dam problem	No method	[83]
Static and dynamic games	Broadband technology (ICT) business	AHP	[85]
Cooperative game	Wastewater management problem	CP ELECTRE I	[91]
	Airlines merging	TOPSIS	[86]
	None	VIKOR	[32]
	Profit allocation	AHP	[87], [97]
	Development of large projects by the board of directors of enterprises	VIKOR	[88]
	Resource allocation	TOPSIS DEA	[89], [90]
	Service quality	COPRAS TODIM	[93], [98]
	Investment problem	Fuzzy VIKOR	[94]
	Cutting device selection	Fuzzy DEMATEL	[95]
	Health condition of transformers	Fuzzy AHP EW	[92]

	Pattern recognition and real cloud service selection problem	VIKOR	[96]
Non-cooperative and cooperative games	Circular economy waste management	AHP	[99]
Evolutionary game	Indian tea industry problem	No method	[100]

Currently, a review of game theory technique and MCDM method frameworks shows that most of the past studies tend to integrate the static game with AHP and TOPSIS methods. However, there is no study that involves dynamic games with AHP while only one study for TOPSIS [80] which used the leader-follower game model. In a cooperative game study, the most used method is VIKOR followed by AHP and TOPSIS. Table 2 shows that the MCDM methods studied in the game theory model.

The study between AHP with the combination of static and dynamic games [85] and the combination of noncooperative and cooperative games [99] is only one, respectively. The number of studies in both, either static and dynamic games or non-cooperative and cooperative games, have not attracted enough attention and the deep investigation is still lacking. In this study, hybrid studies have been reviewed and discussed. Hence, we believe there is more to explore in the dynamic game, cooperative game and combinations of static and dynamic games, and combinations of non-cooperative and cooperative games, and evolutionary game with MCDM methods.

Table 2 The MCDM methods studied in the game theory model.

	Game theory model				
MCDM Method	Static game	Dynamic game	Static and dynamic games	Cooperative game	Non-cooperative and cooperative games
AHP	[45], [48], [50], [55], [56], [58], [59], [65]		[85]	[87], [92], [97]	[99]
ANP	[45], [49]				
DEA	[51]			[90]	
TOPSIS	[52], [56], [60]–[62], [64], [66]–[68], [70]	[80]		[86], [89]	
SWARA	[46], [47]				
WASPAS	[47]				
ELECTRE	[70]	[81]		[91]	
SAW	[54]				
SMAA-GRA	[53], [69]				
AGRA	[65]				
EW	[49], [65], [68]			[92]	
CE	[58]				
ER		[36]			
DEMATEL	[49]			[95]	
PROMETHEE		[84]			
CP				[91]	
VIKOR				[32], [88], [94], [96]	
COPRAS				[93]	
TODIM				[98]	

6. Conclusion

Game theory techniques and MCDM methods are useful to support the evaluation, selection and ranking criteria and alternatives to aid the DMs in making a decision. During the last decades, the integration between these two approaches has been used increasingly to support decision making. In this paper, a comprehensive review of the game theory and MCDM frameworks is discussed and analyzed. At first, the definitions and models of game theory are discussed. Then, the classifications of game theory techniques are introduced. Moreover, the different classifications of game theory technique consisting of static game, dynamic game, a combination of static and dynamic games, cooperative game, a combination of non-cooperative and cooperative games and evolutionary game are studied. Also, the various applications studied in the hybrid game theory and MCDM are discussed. The contribution of this paper in the area of game theory and MCDM studies can aid the researchers effectively in the area of decision making with conflict and compromise to get an optimal solution. Further potential research can be concentrated on the animals' interactions in biological sciences. As a future trend, the dynamic and evolutionary games using fuzzy system and integration with the optimization methods can be considered.

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