CHAPTER 1
INTRODUCTION

The theoretical observation and practical implementation of the Group Decision Making (GDM) have become one of the major areas of research in decision sciences. Over the last decades, the researchers in the field of computer science, decision science, management science, engineering and other disciplines have shown keen interest in developing models and methods of decision making, which helps achieving considerable results. In this regard, this chapter discusses the basic knowledge regarding the decision making based on number of decision makers in general and group decision making, in particular. GDM ensures the participatory role of each and every individual having diverse perspective, knowledge and expertise to be made use of. Unlike the individual decision making, group decision making is considered to be based on the collaborative approach for obtaining the decision. Two basic methods of GDM are discussed: the Aggregation-Exploitation and Consensus Reaching Process (CRP). The Aggregation-Exploitation method being simple does not considers the agreement and cohesiveness of the members of the group whereas the CRP being iterative and dynamic process is used most in decision-making for an effective implementation of the decision solution. Keeping in mind the acceptability and effectiveness of the obtained solution, this thesis concentrates on the consensus-based group decision making, discussed in brief in the chapter. The focus is on the research findings which is the motivation behind the research work. The chapter lists the contributions made in the thesis followed by the discussion on the organization of the thesis. The chapter is the foundation for this thesis and its purpose is to give an edge for further understanding.

1.1 Decision Making

Decision-making is the process of selecting a course of action from a set of available options. To make a decision, one needs various kinds of information, like the details of the problem, the factors affecting the outcome, the constraints, and the scenarios. Above all, the main essence of decision-making is the set of potential outcomes and alternatives to choose from. In addition, a decision-making process that involves evaluating and selecting a course of action by making use of multiple criteria that need to be taken care of in arriving at a decision is called Multi-Criteria Decision Making (MCDM). Thus, within the discipline of decision sciences, decision-making has become popular in various situations where we either want to choose the most suitable alternative or rank the alternatives from best to worst. The decision problem to be solved and the identified set of possible alternative solutions are the inputs to any decisional procedure. For example, the selection of IoT services, as per the requirements, from the pool of available services is a decision problem. In terms of decision-making, MCDM methods can be applied directly or multiple decision-makers can also be involved in an appropriate selection of the service [4]. The latter is referred to as Group Decision Making, while the former is said to be done by a single Decision Maker (DM).

Here a brief description regarding decision process by a single decision maker is being provided in next sub-section, for sake of clarity, and discussion on GDM, which is the main topic of this thesis, would follow thereafter.

1.1.1 Decision Making with Single Decision Maker

A decision making may be done by an individual or a group. Individual decision making is a complex process where the individual makes the decision reasoning about her own needs, capabilities and experiences, regarding the decision problem [1]. It can be more effective in certain situations like: it can be more efficient for an individual to make decision when there is time constraint and the decision needs to be made more quickly rather than waiting for a group. For such a decision making by an individual, academicians and professionals have explicitly applied Multi-Criteria Decision-Making (MCDM) methods to develop the framework for obtaining the solution [2] [3] [4]. The literature of MCDM has a rich set techniques such as AHP (Analytic Hierarchy Process), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), ANP (Analytic

Network Process), ELECTRE (Elimination and Choice Translating Reality), and various Outranking methods which are frequently used by researchers to solve the decision-making problems.

The main elements found in any Single decision-making problem using MCDM methods are as follows:

- A decision problem to solve
- A finite set X of 2 or more feasible alternatives or possible solutions:

$$X = \{x_1, x_2, \ldots\ldots, x_n\}, \qquad (n \geq 2)$$

- A finite set A of evaluation criteria which characterizes the alternatives

$$A = \{a_1, a_2, \ldots\ldots, a_l\}, \qquad (l \geq 2)$$

The values to the alternatives in X are provided with respect to each criterion in C as shown:

$$V = \begin{pmatrix} v_{11} & v_{12} & \cdots & v_{1l} \\ v_{21} & & \ddots & v_{2l} \\ \vdots & & & \vdots \\ v_{n1} & v_{nl} & \cdots & v_{nl} \end{pmatrix} \qquad (1.1)$$

Where $V = (v_{ij})_{n \times l}$ is the preference value of the alternative x_j with respect to criterion a_j. The values can be of different types such as different MCDM method adopts different strategy to solve the problem and the final decision (that is ranking the alternatives) will be made depending upon the method applied.

In the next section the understandings related to group Decision making, the topic of the thesis, are being brought out.

1.1.2 Group Decision Making

This section brings out necessary understandings related to decision-making with multiple decision makers which is called as Group Decision Making (GDM), which is the focus of this thesis. In practice, for several important problems, making decisions with the involvement of multiple Decision Makers (DMs) becomes essential and it is preferred over decision making by an individual, for example in problems such as Software Pricing, GDM is the way to go. Here, the purpose is to involve people from different background, views and knowledge, which widens the perspective of individual decision making. The likelihood of success is enhanced when people implementing the decision are allowed to contribute to shaping the decision and thus creating a sense of ownership. The individuals are required to work with others in group settings in order to make important decisions, for example,

1. In the field of Software Project Management, the team members need to decide upon the project duration, Cost, Effort Price etc. For the design and development of the software require the selection of software technology requires a good deal of inputs from the project team members in terms of their opinion. The organizational, economic, political, and business aspects should be taken into account while deciding possible price of a software, which surely requires the involvement of DMs from various diverse areas along with involving marketing and sales staff, senior management and project managers. Other areas like identification of component and architecture to be used for design of the software system also requires the group of members to make suitable decisions.
2. In the field of Social Networks, the exchange of information and communication among the users are increasingly common. This in turn provides access to the information about the social networks and can also be used to study the social relationships among the DMs, called as social network group decision making (SNGDM). The social relationships among the DMs are taken into consideration where the DMs with more knowledge and experience can influence others in the social network.

3. In the field of Economics, Trade and Commerce, the problem of supplier selection is one of the possible decision problems. The members of the organization come together to form a decision committee and such a decision committee is supposed to work in close collaboration, in order to select, for example, a supplier.

4. In the field of Emergency Management, emergency decision making is an important topic to discuss about. When a disaster occurs, to mitigate the negative impacts and to reduce the associated risks, the emergency decision making is needed. Emergency decision making is serious business and the decision is to be made in limited time and possibly with incomplete information. It may involve a lot of uncertainty and complexity to deal with. Thus requires a group of DMs to sit together for the discussion of dealing with the emergency situation.

In general, the GDM is supposed to be a complex process which requires a structured decision-making process. For a structured and effective group decision making, it is important to consider the opinions of individuals and establish shared goals. Group decision making can be defined as a task to find a common solution to a decision problem by aggregating and consolidating the opinions provided by the DMs regarding the set of alternatives. The DMs characterized by their own ideas, knowledge and backgrounds express their opinions for the multiple available alternatives. The likelihood of success is enhanced when people implementing the decision are allowed to contribute in shaping the decision, thereby creating the sense of ownership. Therefore, the approach to decision-making should have the following characteristics: it should be simple and easy in nature, adaptable to both groups and individuals, and more importantly should promote consensus building among the group members [5]. A general framework of GDM is shown in Fig. 1.1.

In order to solve the GDM problem, several DMs with different motivations, and knowledge are invited to participate in solving the decision problem to achieve a common global solution to a problem. The idea behind the involvement of multiple DMs is to get better and less biased solutions than those made by the single DM. The main elements found in any GDM problem are as follows:

- A decision problem to solve
- A finite set X of 2 or more feasible alternatives or possible solutions:

$$X = \{x_1, x_2, \ldots\ldots, x_n\}, \qquad (n \geq 2)$$

- A finite group of DMs d, who attempt to find a final collective solution to the problem by expressing their opinions on the set of possible alternatives X:

$$d = \{d_1, d_2, \ldots\ldots, d_m\}, \qquad (m \geq 2)$$

Each DM $d_p \in d, p = 1, \ldots\ldots m,$ provides his/her opinions on the available alternatives in X by means of a preference structure. Let V^p $(p = 1,2, \ldots, m)$ be the opinion on X provided by DM $d_p \in d$. The goal of group decision making is to combine the individual's opinion V^p $(p = 1,2, \ldots, m)$ using an aggregation function F to obtain a collective preference V^c on X, i. e.,

$$F(V^1, V^2, \ldots, V^m) = V^c \tag{1.2}$$

The aggregation function and the preference representation structure are the two key elements that plays a vital role in the GDM. The aggregation function aggregates the individual's opinion into the collective opinion, which indicates the group opinion. The preference representation structure is discussed in detail in Chapter 2, used to represent the individual's opinion and the group opinion.

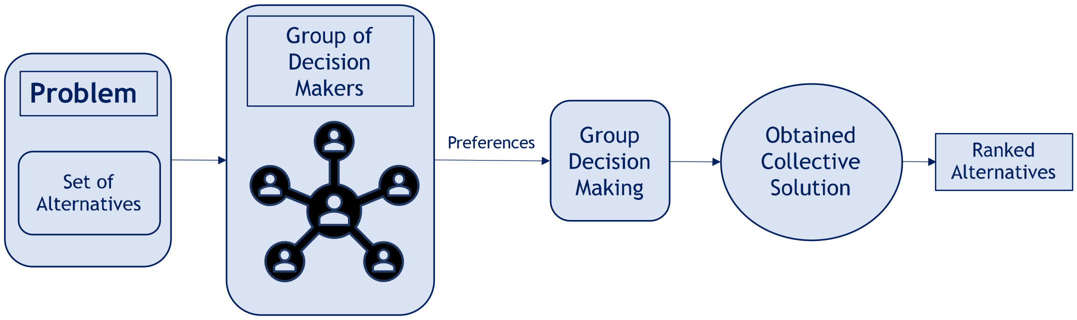

Fig. 1.1: A General Framework of Group Decision Making

1.2 Approaches to Group Decision Making

This section discusses two possible approaches to solve the decision-making problem involving multiple decision-makers: first, the GDM without Consensus which is Aggregation and Exploitation approach and second, GDM involving a Consensus Reaching Process (CRP). Our exploration centres around the idea of the consensus approach, which is attracting interest of researchers and professionals alike. This thesis seeks to explore and address some possible concerns in GDM that result into important research questions and propose possible appropriate Consensus Reaching Processes models for the purpose.

1.2.1 GDM without Consensus

This method consists of two phases shown in Fig. 1.2: First, the aggregation phase which is used to combine the preferences of the DMs. Second the exploitation phase which is used to obtain the set of solution alternatives for the defined decision problem. This approach does not necessarily check any agreement among the DMs before combining the preferences and obtaining the solution for the GDM problem. Therefore, there is a possibility that the proposed solution will not be accepted by some of the DMs, if they feel that there provided opinions have not been taken into consideration in the solving process. However, there are decision problems needing cohesiveness and collaboration on the agreed solution will require an extra phase in the decision process, called as the consensus phase. Such a phase addresses the maximum degree of agreement among the DMs on their preferences before reaching a solution.

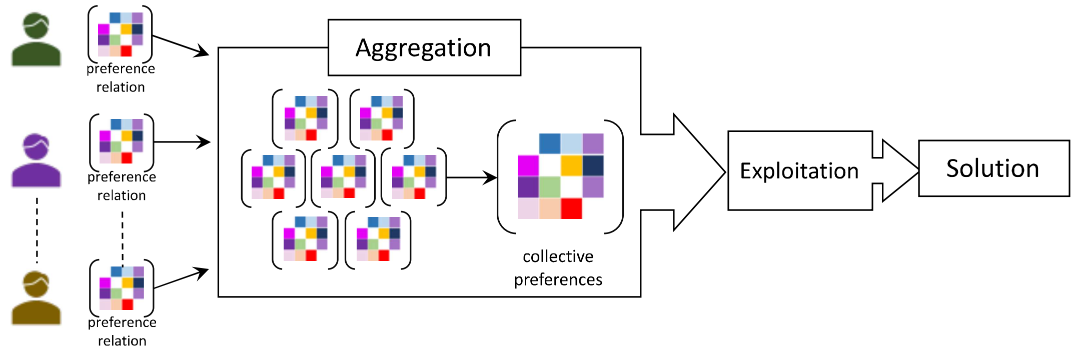

Fig. 1.2: The Aggregation-Exploitaion

1.2.2 GDM with Consensus

The GDM model mentioned in Eq. (1.2) fails to guarantee the agreement among the DMs when obtaining a collective solution to the given GDM problem. However, in many of the real-world decision-making scenario, obtaining a solution which is acceptable and supported by most of the DMs is important. For that having a structured way to align the understandings of the DMs for a complex decision problem for creating a coordinated group action is important.

In general, the CRP is an iterative and dynamic process involving several discussion rounds. At each round, the DMs are expected to modify their preferences according to the advice generated by the moderator. The moderator plays a key role in the consensus reaching process. Generally, the interactive process in CRP is guided by a moderator who gathers individuals' opinions to form group opinions. The moderator is responsible for identifying the inconsistent DMs and encouraging them to adjust their opinion that aims to achieve a high consensus level [6]. The main aim of CRP is to obtain the collective solution with a consensus [7]–[9]. The CRP consists of two processes: consensus measure and the feedback process. The consensus measure is a method of computing the degree of agreement among the DMs whereas the adjustment advice is generated in the feedback process. The literature reports various methods to calculate consensus [7], [10]. An overview of the various phases of the CRP guided by the moderator is discussed as follows.

With the integration of consensus process in the GDM, some key advantages are offered that can be observed as follows:

- The implementation of the GDM becomes more effective. This is because when the preferences and concerns of the DMs are taken into consideration, likelihood of success of the obtained solution is enhanced. The DMs has the sense of ownership as they are allowed to contribute in shaping the decision.
- Consensus helps building connections among the DMs. With consensus as a decision tool means sufficient time taken to make every participant agreeable on the way to proceed before being moving forward. Thus, it promotes the interaction among the DMs.

1.3 Group Decision Patterns

Decision-makers can express their opinion in group decision making using two possible structures: preference relation and multi-attribute based structure. Based on these two structures, in literature, Preference Relation Based GDM (PRGDM) and Multi Attribute GDM (MAGDM) design patterns of decision making are observable in both the GDM approaches of 'With' and 'Without' consensus. MAGDM involves evaluating and selecting a course of action by making use of multiple criteria, that need to be taken care of in arriving at a decision, through a preference representation format in form of a multiple attribute decision matrix. In case of PRGDM, DMs provide their preferences on all pairs of alternatives and the preference representation format in form of representation termed as Preference Relation (also known as Pairwise Comparison Matrix). Without loss of generality, we have considered the PRGDM decision pattern of representing preferences.

1.3.1 GDM in Multi Attribute setting (MAGDM)

The GDM problem in multi-attribute context can be described as follows:

- A finite set X of 2 or more feasible alternatives or possible solutions:

$$X = \{x_1, x_2, \ldots\ldots, x_n\}, \qquad (n \geq 2)$$

- A finite set A of 2 or more attributes:

$$A = \{a_1, a_2, \ldots\ldots, a_l\}, \qquad (l \geq 2)$$

- A finite group of DMs d, who attempt to find a final collective solution to the problem by expressing their opinions on the set of possible alternatives X:

$$d = \{d_1, d_2, \ldots\ldots, d_m\}, \qquad (m \geq 2)$$

Let $W = \{w_1, w_2, \ldots\ldots, w_m\}$ be the DMs weighting vector where $w_p \geq 0$ be the weight associated to the DM d_p and $\sum_{p=1}^{m} w_p = 1$. Let $\omega = \{\omega_1, \omega_2, \ldots\ldots, \omega_l\}$ be the weighting vector of the criteria, where $\omega_k \geq 0$ be the weight associated to the attribute a_k and $\sum_{k=1}^{l} \omega_k = 1$. Let $V^p = (v_{ij}^p)_{n\times l}$ be the multiple attribute decision matrix provided by the DM d_p, where v_{ij}^p represents his/her preference value for the alternative x_i with respect to attribute a_j, given in Eq. (1.3)

$$V_p = \begin{pmatrix} v_{11}^p & v_{12}^p & \cdots & v_{1l}^p \\ v_{21}^p & & \ddots & v_{2l}^p \\ \vdots & & & \vdots \\ v_{n1}^p & v_{n2}^p & \cdots & v_{nl}^p \end{pmatrix} \qquad (1.3)$$

Above all, the decision objective of the MAGDM is to determine the rank of the alternatives, based on the multiple attributes-based decision matrices $V^p = (v_{ij}^p)_{n\times l}$

given by some DM d_p. It is to note here that in case of decision making with an individual, the value of $m = 1$, i.e., d consists of only one DM.

1.3.2 GDM in Preference Relation setting (PRGDM)

Preference relations is one of the preference representation structure widely used by the DMs to provide their preferences, discussed in detail in Chapter 2.

The GDM problem in preference relation context can be described as follows:

- A finite set X of 2 or more feasible alternatives or possible solutions:

$$X = \{x_1, x_2, \ldots\ldots, x_n\}, \qquad (n \geq 2)$$

- A finite group of DMs d, who attempt to find a final collective solution to the problem by expressing their opinions on the set of possible alternatives X:

$$d = \{d_1, d_2, \ldots\ldots, d_m\}, \qquad (m \geq 2)$$

The DMs provide their preferences on a set of alternatives using pairwise comparison matrices. It is represented by $V^p = (v_{ij}^p)_{n\times n}$ which is the preference relation provided by DM d_p where $v_{ij}^p \in [0,1]$ in case of fuzzy preference relation represents his/her preference relation of alternative x_i over alternative x_j, given in Eq. (1.4)

$$V_p = \begin{pmatrix} v_{11}^p & v_{12}^p & \cdots & v_{1n}^p \\ v_{21}^p & & \ddots & v_{2n}^p \\ \vdots & & & \vdots \\ v_{n1}^p & v_{n2}^p & \cdots & v_{nn}^p \end{pmatrix} \tag{1.4}$$

The decision objective of the GDM in preference relation setting is to obtain the ranks of the alternatives. For simplicity, we follow the fuzzy preference relation approach (also called as additive preference relation) in our work.

Note: As already discussed, a group may consist of two or more members. If a group consists of two members, they can directly communicate with each other and in case of three or four, such communications may also be sustained. But as the group size keeps on increasing, the role of moderator becomes inevitable. It receives and accumulates the preferences of the DMs for working out the feedback suggestion to each of the individual inconsistent DM with the purpose of smoothening the communication; Conversely, having too many DMs leads to too many conversations between different DMs that may result in complex decision-making processes and unclear conversations. Under such circumstance, the message complexity would be $O(m^2)$ for single iteration where, m is the number of DMs, who would overwhelm the decision-making process. This emphasises the relevance of moderator who simplifies the decision-making process among the DMs. The moderator usually carries out the following tasks in the CRP: gathers the opinions, calculates the degree of consensus, verifies the degree of consensus, and provides feedback advice to the DMs to modify their preferences if they need to do so.

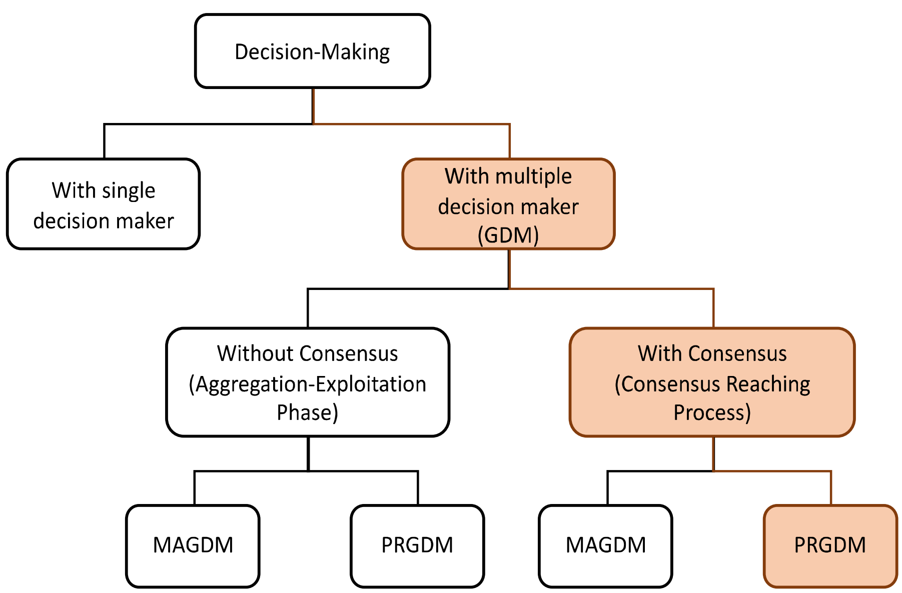

Fig. 1.3: Overview of Decision-Making

Fig. 1.3 provides an overview of decision-making based on number of decision-makers. The figure shows the setting of work on GDM in this thesis identifying place of PRGDM and CRP, in the big picture, as main elements of focus. Under the decision-making field, our focus is on Consensus-based Group Decision Making in Preference Relation setting. Consensus building is the key process of the GDM problems. CRP in GDM is used to get a certain degree of agreement among the DMs who state, negotiate, and modify their preferences. However, reaching a consensus requires discussion rounds implemented by the feedback mechanism. The challenge is to design a feedback mechanism that aids CRP in reaching consensus with minimal rounds of discussion. The research content of the thesis is carried out around the key process i.e., consensus only.

1.4 Research Questions

Consensus Reaching Process is an effective method for solving decision problem that involves multiple individuals to collectively make a decision ensuring higher level of their satisfaction. Despite numerous researches in the consensus-based decision making, there is still much to be understood regarding the factors that may influence the quality of decision making. Consequently, the following research questions need to be addressed:

RQ1: GDM usually considers the opinions of DMs, who generally are the experts in their respective areas. However, with the ever-growing communication and information technology, the non-experts, such as end service users, even though unstructured, also have knowledge and experience. Consequently, their awareness may be helpful, and such people may be interested in providing their opinions. Hence the question, “Can we consider the opinion of non-experts along with the opinion of experts to further enhance/enrich the consensus among the experts?”. If it can be done, then how?

RQ2: The CRP for the decision-making may have an undefined number of iterations to reach a consensus. In contrast, there are situations like emergencies in which a consensual decision at the earliest may be desirable. Consequently, the question regarding obtaining the consensus in one go needs to be explored.

RQ3: CRP presumes the continuous availability of the DMs during the decision-making process, whereas, in realistic situations, one or more DMs may not be available in each of the iterations. Hence the question regarding obtaining a consensus when one or more DMs become unavailable sometimes becomes relevant.

RQ4: It is evident that the collection of preferences, their processing, and the dissemination of the feedback must be done by a centralized authority, called a moderator, which might be questioned regarding trust and security in the Group Decision Support System (GDSS) facilitating the decision-making process. How to ensure trust and security in such a situation of a group decision-making process?

This thesis aims at answering all the raised questions regarding consensus-driven group decision-making by proposing some new CRP methods. The main objective of this thesis is as follows:

- Study of several existing CRP methods and identify the various issues resulting from breaking some of the assumptions in CRP that need to be addressed to improve the overall systems' performance and management.
- Design some CRP methods to address the identified issues to improve the quality of the decision-making process and decision quality.
- Analysis, simulation, and characterization of the newly designed CRP methods and comparison with the known representative CRPs.

In the context of the above research questions, we have proposed the following relevant models for addressing the problems emanating from the concerned research questions. These are as follows:

i. Consensus model with customized feedback-based Group Decision Making involving heterogenous DMs

ii. Consensus model with tolerance-based moderator guiding heterogeneous Group Decision Making involving experts and end-users
iii. Consensus Model to manage Unavailability of Decision-Maker sin Group Decision Making
iv. Decentralized Group Decision making using Blockchain

1.5 Motivation

Although the data, and the associated quantitative modeling, may be used to drive the decision-making processes, the relevance of human guidance made available to DMs providing qualitative information may purposefully enhance its effectiveness when a consensual solution is required. With the ever-growing technological expansion of the world, GDM has found its application in several real-world problems, such as software engineering [19], emergency decision-making [18], social media [17], and e-democracy [16] are some examples. For example, in software engineering, software pricing has to be a group activity involving marketing and sales staff, senior management, project managers, etc. In the first phase of the software project development, requirement gathering calls for group decision-making to ensure completeness and consistency. Eventually, numerous researchers conducted extensive research on GDM in such application areas with notable consequential results.

The ongoing research efforts aimed at the application of GDM in such areas as mentioned above provide the motivation of the research for identifying relevant research questions and obtaining solutions to the problems identified in this context. Various researchers have reported valuable techniques in the past decade providing notable solutions to GDM problems. However, there are still some research challenges as well as gaps that need to be addressed, and hence the following issues concerning the GDM need further investigation and discussion:

Different GDM models, including several experts as decision-makers, have been proposed in the literature [20][11]. In socio-technical systems such as smart cities [21], the input from the citizens defines the dynamics of the city. The end-users of a service provide preferences according to their good or bad experience. The experts may benefit from the end user's opinion and may gain insight into valuable social settings, which is usually overlooked. Thus, it becomes necessary to embrace the new ideas and advice of the non-experts as input to decision-making, called as heterogenous decision making that truly benefits all concerned

- For reaching a consensual agreement, the CRP may experience an undefined number of iterations with the feedback involved in each of them. However, in cases such as decision-making in emergency management, a quick decision at the earliest may be desired. Therefore, some suitable strategy needs to be explored for this purpose.
- All the known GDM models assume continuous availability of all the DMs during the CRP for achieving consensus. However, in a realistic situation, one or more DMs may be unavailable at times in CRP iterations. Thus, it is pertinent to work out a model that can take care of such absences and eventually make GDM possible.
- The collection of preferences, their processing, and dissemination of feedback have to be done by some central node, which may become vulnerable to security risks and attacks. It would be interesting to look for some decentralization to be able to coordinate the consensus process effectively, getting rid of security risks and consequently improving the trust of DMs in the consensus process.

The literature on GDM needs to be enriched by addressing the above issues and hence these issues form the motivation for this research work.

1.6 Contributions

In this section, the important propositions made by this work are presented. The key contributions, including design, implementation and the comparative analysis of the proposed GDM models for addressing the identified issues of group decision-making, are as follows:

i. *A 2-phase consensus with customized feedback-based Group Decision Making involving heterogenous DMs:* addresses two issues, one the heterogeneous decision-making and the other the undefined number of feedback iterations. A GDM model is proposed to deal with the heterogeneity of DMs, providing personalized advice to the DMs so that the consensus is achieved at the earliest. The proposed model offers feedback suggestions with the help of a predefined consensus threshold to achieve consensus in one go.

ii. *A tolerance-based moderator guided heterogeneous Group Decision Making involving experts and end-users*: A GDM model is proposed that takes into account the consensual opinion of experts and the cumulative opinion of end-users to obtain a global consensual decision. The model considers a tolerance-based moderator to limit the difference between the experts' consensual solution and the final decision. The developed method is found to be effective in balancing the preferences of both the experts and the end-users, thus making it conducive to modifying the expert's consensual agreement in the final decision generation.

iii. *Managing unavailability of Decision Makers in Group Decision Making:* A decision-making framework based on the self-management mechanism to manage the availability of DMs in the CRP is proposed. The framework considers not only the preferences of the available decision-makers but also those of any unavailable ones when evaluating consensus in a particular round. Due to the consideration of the unavailable

DM's opinion based on their bounded confidence, there is a decrease in the number of rounds to reach consensus even when the DMs leave and join at times.

iv. *Considering Security and Bias in Group Decision Making:* A decentralized group decision-making using blockchain is proposed to overcome the challenges of the existing centralized decision-making systems. The primary goal of this study is to present and analyze the issues of the conventional Group Decision Support Systems (GDSS), which are of high importance in reflecting the future of blockchain-based GDM systems. An architecture of the decentralized GDM system involving DMs interacting with the Ethereum Blockchain smart contract, and administering the GDM process is proposed.

1.7 Thesis Organization

In this research work, several issues have been identified regarding group decision-making in general and the consensus-reaching process in particular. Several consensus-based GDM models have been proposed to address those identified issues, and accordingly, the research papers are written. The thesis work is divided into the following chapters to project the contributions made clearly and for better understanding. Chapter 1 states the basic introduction of Group Decision Making. Chapter 2 contains the preliminary knowledge and the associated literature survey. After that, the key contributions of the thesis start from Chapter 3, followed by Chapter 4, Chapter 5, and Chapter 6. At last, Chapter 7 summarizes the thesis with the conclusion and future research directions identified. A graphical representation of the outline of the thesis is depicted in Fig. 1.4.

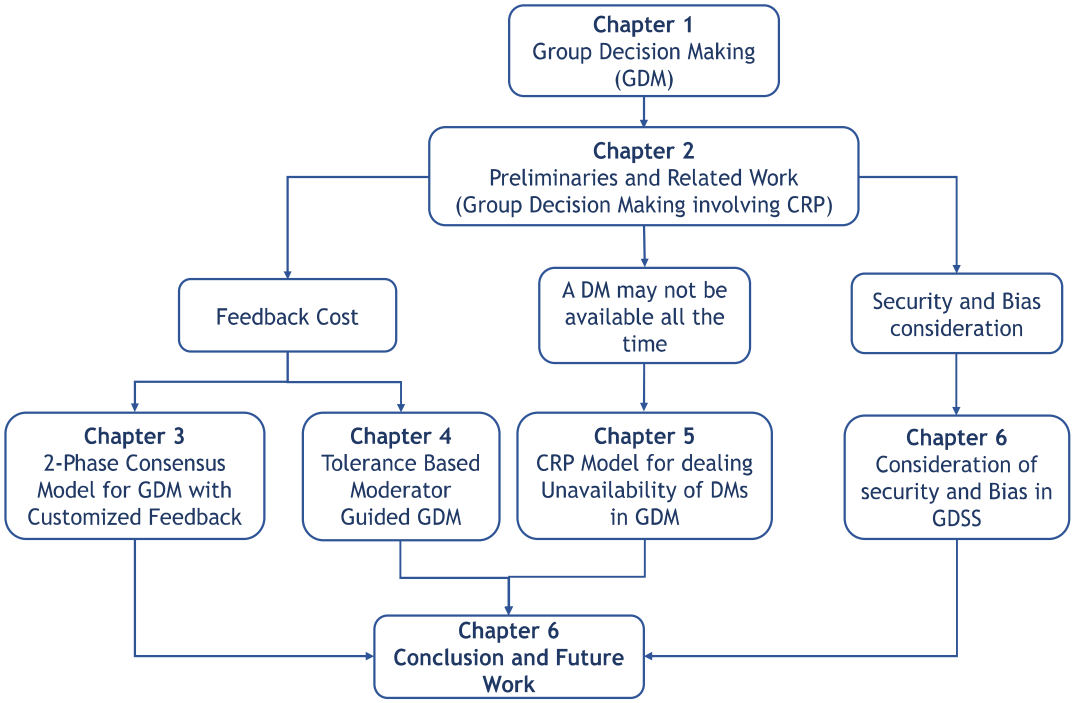

Fig. 1.4: Thesis Structure

A brief description of the each of the Chapter discussed in the thesis is as follows:

Chapter 2: Preliminaries and Literature Review. This foundation-oriented chapter presents the basic knowledge regarding group decision-making, consensus-reaching process, and blockchain technology. Then, it presents the literature survey related to consensus-based group decision-making and identifies the issues and research gaps in the existing consensus-reaching processes for decision making.

Chapter 3: 2-phase consensus with customized feedback-based group decision making involving heterogeneous decision makers. This chapter presents a novel 2-phase consensus with customized feedback-based group decision-making involving heterogeneous decision makers. Two phases of the consensus-reaching process are defined: the inter-consensus reaching phase and the intra-consensus reaching phase to deal with the heterogeneity in the context of decision-makers.

Chapter 4: Tolerance based moderator guided heterogeneous group decision making involving experts and end-users. This chapter presents a novel threshold-based feedback mechanism with the idea of providing flexibility to the moderator while generating a global consensual decision in the presence of experts' and end-users' opinions simultaneously.

Chapter 5: A Consensus Model to manage Unavailability of Decision-Maker sin Group Decision Making. Traditional decision-making scenarios consider that decision-makers are present/available in every consensus round until one achieves a consensual decision. However, one or even more than one DM may leave and join the process at times, especially in interactive decision-making. In this chapter, a CRP is proposed making use of the bounded confidence concept to manage the partial availability of the DMs.

Chapter 6: Decentralized Group Decision making using Blockchain. This chapter considers the security aspect of the Group Decision Support Systems and the moderator's biased behavior. For this purpose, a decentralized approach for GDM supported by blockchain technology is proposed. An architecture of the decentralized GDM system is proposed that involves DMs' interaction with the Ethereum Blockchain smart contract administering the decision-making process. This work is the first decentralized GDM using blockchain to our best knowledge.

Chapter 7: Conclusion and Future Research Directions. This thesis ends with some important conclusions by summarizing the main findings of the work done herein and possible future research directions.