CHAPTER 7
CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This chapter concludes the thesis ascribing the outcome of the research. It also gives possible future research direction that may further be pursued.

7.1 Conclusion

We started the work by introducing Group Decision Making (GDM) in terms of concepts, known approaches, and available models as known in the literature. In such models, initially, the group members provide their opinions which undergo the aggregation and exploitation phase. Such members of the group are considered experts who have special knowledge and experience as may be warranted for meaningful decision-making. A Consensus Reaching Process (CRP) is deployed in a GDM for the purpose of obtaining a consensual decision. The consensus process aims at provisioning preferences over a set of alternatives by DMs and achieving an agreement over a collective opinion before coming up with a decision. It is a dynamic and iterative process that consists of several rounds of discussion and modification of preferences by the DMs. Such a traditional model of CRP requires a moderator to review the collective opinion and generate feedback suggestions to the inconsistent DMs. This is to ensure that the consensus process is properly examined. In this thesis, we have worked on consensus-based group decision-making and proposed four CRP based-GDM models to overcome several research gaps, as discussed in Chapter 1.

Chapter 1 of the thesis discussed group decision-making and the consensus-reaching process and showed how it plays an important role in solving decision-making problems. This chapter detailed the motivation behind this thesis work and the identified research gaps in the existing CRP methods to solve decision-making problems. Further, this chapter lists the thesis's objectives and the contributions made.

To solve the identified research problems, we examined the various CRPs by performing a comprehensive literature survey. Chapter 2 defines the basic knowledge regarding GDM required to understand the CRPs and discusses the literature review of the CRPs with their theoretical background. By doing that, the issues related to the existing CRPs are identified. To streamline the survey process, we divided the existing CRPs into four parts: CRPs for heterogeneity of DMs, CRPs for feedback cost, CRPs for unavailability of DMs, and decision support systems for trust and security issues. A detailed description of these approaches is discussed in the chapter.

The literature review found that heterogeneity regarding the type of DMs is rarely considered in GDM. Most existing models assume that the DMs with expertise in their respective areas are the only participant in the decision-making problem. However, it would not be reasonable to involve only experts in the decision-making; instead, the participation of non-experts can help improve the overall insight into the decision-making problem. Chapter 3 discusses a CRP model involving non-experts and experts as decision-makers, known as heterogenous decision-making. In addition to addressing the heterogeneous decision-making problem, this chapter also addresses the issue of feedback cost. To deal with the problem of feedback cost while considering the heterogeneous DMs, a 2-phase CRP involving the inter-consensus reaching phase followed by the intra-consensus reaching phase is designed. The inter-consensus reaching phase deals with achieving consensus between experts and non-experts, whereas the intra-consensus reaching phase only builds consensus among experts. The main ingredient in both phases is the design of the feedback mechanism, depending on the consensus threshold value, which helps CRP reach an agreement at once, provided the DMs show cooperative behavior. By that, the feedback cost is reduced and overcomes the challenge of fixing the maximum number of rounds to reach a consensus. This is done by generating customized suggestions that are accurate enough to reach a consensus at once. As a result, the proposed feedback mechanism converges to consensus more quickly than the classical CRP. Hence, the proposed GDM model is equally effective in reaching a consensus for the classical GDM when only experts are considered and for emergency decision-making, which is to be done in a limited time.

Next, Chapter 4, while addressing the research issues discussed in Chapter 3, adds a dimension providing flexibility to the moderator responsible for regulating the CRP. In this chapter, the considered DMs are the end-users and the experts. The end-users are assumed to be the resource person whose ideas are used in the GDM. In the proposed GDM model, cumulative end-users' opinion and consensual experts' opinions, called ExCS and EuCS, respectively, are computed explicitly. Once ExCS and EuCS are obtained, the final solution, called global consensual solution GCS, is generated with the help of a moderator. In context to generating the GCS, the moderator is associated with the tolerance degree, which controls the degree of deviation from the reference solution, EuCS. The value of tolerance defines the inclination of GCS towards ExCS and EuCS. The moderator is reluctant to change the expert's consensual opinion for a smaller tolerance value, implying that the final decision will purely rely on the experts' opinions.

In contrast, the maximum deviation from the ExCS is observed for a large tolerance value that the moderator can tolerate. In relation to that, the impact of users' opinions on the final decision GCS is observed using Spearman's Rank Correlation Coefficient to measure the correlation between the EuCS and GCS, and ExCS and GCS, which shows that the final decision would be more accurate and possibly better accepted than when users' opinion not incorporated. The proposed method behaves as classical

GDM that works through aggregation and comprehension of the users' experience for decision-making in the case when the number of experts becomes zero.

The literature survey found that the existing CRPs assume the continuous availability of DMs in the decision-making process. However, due to technical or non-technical reasons, a DM may become unavailable at times, i.e., sparsely available in the process while building consensus. Chapter 5 addresses this issue of the unavailability or sparse availability of DMs in the active decision-making process. To address this issue, we proposed a CRP model to examine the opinions of temporarily unavailable DMs and those available at that instance. Since the DM, whose unavailability is high, would lack understanding regarding the decision-making problem. Thus, to ensure the quality and mature decision, high credence is provided to those who are relatively more available, and thus, a dynamic weighting method is presented to address this issue. For such an unavailable DM, the proposed method uses their bounded confidence to automatically generate their preferences. The detailed simulation analysis is shown in the chapter to show the proposed method's effectiveness. The observations are, firstly, the average rounds to reach consensus increase with an increase in the number of DMs. This is because, with an increase in the number of DMs, the diversity of opinions adds complexity and increases consensus rounds. Secondly, the average round to reach consensus increases as the number of DMs increases, which means that the speed of convergence to consensus will slow down when the number of DMs increases, as it is obviously expected.

The centralization of the GDSS platform may result in several issues, such as vulnerability to single-point failure, security and privacy risk. The alternate solution is a decentralized system with no single party owning the complete network. Blockchain technology can be leveraged as a possible solution to decentralize the GDSS, which is discussed in Chapter 6. This holds several advantages compared with the centralized GDM systems. To provide DMs with a more secure and trustful platform, a decentralized GDM system using blockchain is proposed, facilitating the distributed decision-making and consensus-building process and for the effectiveness of the CRP, introducing a consensus-reaching process in the decentralized GDM to minimize the gas cost charged on a public blockchain Ethereum. To validate the proposed decentralized GDM, we implemented the proposed CRP on the Ethereum blockchain that requires a fee, known as Gas, to execute transactions. The proposed CRP reduces the transaction fees paid on the public Ethereum Blockchain. Moreover, the gas cost analysis shows that the proposed decentralized GDM is less costly in terms of Gas than the traditional GDM process. The security analysis of our proposed GDM system and the achieved security goals are also presented. The obtained experimental results indicate that the proposed CRP could reach a consensus with at most one round of feedback and thus reduce feedback cost and gas costs.

The application area of the discussed GDM is wider. In many places, including software project management, GDM is used for various purposes. For example, experts and managers should consider the organizational, economic, political, and business considerations and collectively decide on a possible price for a software product/service. Because in the case of new products or services, the behavior of the consumer, the competitors, or the other market factors are full of uncertainties like technology acceptance, which makes the pricing decision a critical puzzle that needs to be solved by multiple DMs with their assessments. The DMs provide preferences based on their knowledge and beliefs, which are aggregated for giving feedback to each DM to enable them to incorporate changes in their preferences for all possible decision instances. This may be done in multiple iterations until they arrive at a consensus. Here, it should be noted that the thinking process of an individual DM to give the preference in the first round of iterations, considering feedback after every iteration, and incorporating modification in the preference in the subsequent iterations, for all these human activities of DMs and hence no algorithmic description of the same would be possible. Thus, the GDM system with a central node facilitates the collection of preferences and the formation of feedback through a communication arrangement. Since the thought process of the mind of a DM has no algorithmic description (just as halting problem studied in Algorithms in Computer Science doesn't have any algorithmic solution, and even infinite time would not suffice to solve that problem [120]) and therefore, working out preferences regarding possible decision alternatives cannot be carried out by a machine. Traditionally, group decision has been in operation research, decision sciences, and so on.

7.2 Future Research Directions

Although GDM is an interesting research topic, it is still in its early stage of development. Unlike most studies on GDM, this thesis argues that the incorporation of non-experts like end service users and considering the feedback cost regarding the number of consensus rounds to achieve group consensus are critical for consensus building. Moreover, the idea of a decentralized group decision-making structure is also one of the pertinent research propositions, which is also discussed here in this thesis. Therefore, the following future research directions on GDM can be observed to continue this research idea.

- Extension to large-scale decision-making: Classically, the GDM problem occurs in most organizations at a strategic level, in which a small number of people are responsible for making the decision. However, with the development of Web 2.0 and the expansion of technological paradigms such as social media and e-marketplaces, the so-called large-scale GDM (LSGDM) problems, in which a more significant number of DMs can participate, attain greater importance. With many DMs interacting through social media platforms, a social relationship among the DMs can be observed, which is crucial in forming the DMs' opinions. The relationship argued in the literature is the trust relationship which plays a vital role in consensus-building in the LSGDM and cannot be ignored. Hence the future research direction is extending the proposed models with the idea of large-scale trust relationships are the research directions that can be looked upon.

- The balance between the DM's behavior and the feedback cost: This thesis considers that the DMs are cooperative, meaning they all accept the feedback recommendation and modify preferences accordingly. However, the DMs may also reflect non-cooperative behavior in realistic decision-making situations. They may show reluctance to adjust preferences as required instead of modifying as opposed to the advised feedback direction or do not change their preferences at all, thus increasing the feedback cost. This behavior of the decision maker may be detrimental to achieving consensus at once, and hence the improvement of group consensus level is prevented. Therefore, the game between the feedback cost and the DMs behavior should be further discussed in the future.
- Tolerating the non-cooperative behavior: As considered that the DMs are cooperative in nature, meaning thereby that they are consensus ready. However, this is not always true. The DMs may not be consensus ready and thus shows non-cooperative behavior hindering the achievement of consensus in any possible way. Hence the question is how many non-cooperatives can be tolerated for a given set of DMs to arrive at a group consensus. In any of our proposed models, the consideration of non-

cooperation is neglected. Therefore, if we extend the proposed models, the behavior analysis of the DMs could be a possible future work to study.

- Limitations of the number of participants: The number of decision-makers involved in the case studies or the numerical examples shown for demonstration of the proposed model in this thesis is mostly 8 or 10. The question is whether the consensus models presented in this thesis still apply to the problems of decision-making involving large group decision makers like 50 or 100. This indeed is a significant research problem, and also it is necessary to enhance the usability and improve the adaptability of the proposed GDM models.
- Ensuring privacy in GDSS: The traditional GDM works on the understanding that the individual DMs do not get to know about preferences furnished by any other DM individually. Rather, a centralized system furnishes the sort of aggregation of preferences for providing feedback to each of the decision-makers. With the decentralization of the GDSS using blockchain, a straightforward method works in terms of maintaining all the preferences at all the decision-makers nodes. This raises the issue of privacy undermining the users' anonymity, confidentiality, and privacy control in the transactions (i.e., exchange of preferences). Thus, to tackle the privacy issues, the proposed model in Chapter 6 can be extended to propose a privacy-preserving solution for blockchain-based GDSS.