Research on Decision-Making Consensus Methods for Groups of Different Scales and Visualization of the Discussion Opinions Convergence Process

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Abstract: With the continuous and rapid development of big data, cloud computing, and artificial intelligence technologies, a large number of complex giant systems have emerged in various fields of society. Faced with complex decision-making problems, theories and methods related to group consensus decision-making have gradually become a research hotspot. Aiming at the deficiencies in existing group consensus decision-making research, such as poor method universality, difficulty in intuitively displaying the opinion convergence process, and large gaps in decision-making efficiency among groups of different scales, this paper conducts a systematic study on multi-scale group consensus decision-making methods and the visualization of the dynamic convergence process of discussion opinions. The experimental results show that the scale-adaptive consensus decision-making model constructed in this paper can effectively improve the consensus formation efficiency of various groups and reduce the consumption of the decision-making process. Meanwhile, the built visualization system can fully display the whole process of opinion evolution and convergence, providing an intuitive basis and technical support for the optimization and adjustment of group decision-making schemes.

Keywords: Group Consensus; Decision-Making Method; Expert Collaboration; Cluster Analysis; Visualization

1. Introduction

Group consensus decision-making is a decision-making process in which multiple decision-makers interact, negotiate, and compromise to gradually reach a consistent cognition around specific goals. It is widely used in public policy formulation, enterprise strategic planning, academic seminars, emergency management, and other fields. With social complexity and organizational diversification, the scale of group decision-making presents diverse characteristics, ranging from project decision-making in small teams, scheme review in medium-sized organizations, to policy seminars with large-scale public participation. The decision-making needs, interaction modes, and degrees of opinion divergence of groups of different scales are significantly different. At present, existing group consensus decision-making methods fail to fully consider the inherent differences among groups of different scales, leading to low decision-making efficiency and poor consensus quality: small-scale groups are prone to opinion polarization or blind compromise due to the small number of members and frequent interactions; medium-scale groups struggle to quickly focus on core divergences due to scattered opinions and high coordination costs; large-scale groups are prone to consensus stagnation or decision-making lag due to strong member heterogeneity and massive and messy opinions. In addition, the convergence process of discussion opinions is mostly in a "black box" state, making it difficult for decision-makers to intuitively grasp the dynamic evolution of opinions, focus points of divergence, and progress of consensus promotion, and thus unable to adjust decision-making strategies in a timely manner, further exacerbating the difficulty of reaching consensus. As an effective means to solve information clutter and improve cognitive efficiency, visualization technology has been gradually applied in the field of group decision-making, such as presenting static indicators like opinion distribution and consensus degree through charts. However, existing visualization schemes mostly focus on displaying consensus results, lack the depiction of the dynamic process of opinion convergence, and cannot clearly present key information such as individual opinion adjustment, group divergence evolution, and consensus promotion path. Therefore, constructing adaptive consensus decision-making methods according to the decision-making characteristics of groups of different scales and designing scientific and intuitive visualization schemes for the opinion convergence process to solve the pain points of group consensus decision-making of different scales and improve the scientificity, efficiency, and transparency of decision-making have become important research topics urgently to be solved in the current group decision-making field.

2. Research Status at Home and Abroad

Foreign research on group consensus decision-making started early and has formed relatively rich research results. Early research focused on the basic theories and processes of consensus decision-making, proposing classic methods such as the Delphi method and the nominal group technique [1,2]. Among them, the Delphi method effectively reduces the impact of group pressure on decision-making through anonymous feedback and multi-round consultations, and is suitable for expert group decision-making, widely used in business, military, education, and other fields; the nominal group technique ensures the fairness of members' speeches through a structured process and can quickly achieve opinion convergence, suitable for small and medium-scale groups. In recent years, with the development of artificial intelligence and big data technologies, scholars have begun to explore intelligent consensus decision-making methods, such as consensus reasoning methods based on Bayesian networks and consensus guidance methods based on reinforcement learning [3,4]. These methods improve the efficiency of consensus formation by quantifying opinion divergences and optimizing negotiation strategies, but most of them fail to fully consider the differences in group scales and have insufficient adaptability. In addition, foreign scholars have also paid attention to psychological factors in group decision-making and proposed consensus methods based on psychological gap measurement[5], which quantify decision-makers' acceptance of group opinions and provide support for consensus guidance. Foreign research on group opinion convergence mainly focuses on convergence mechanisms and influencing factors. Scholars have analyzed the impact of individual opinion adjustment and group interaction on the convergence process by constructing opinion dynamics models[6], such as research on opinion convergence based on the bounded confidence model, revealing the influence law of confidence thresholds on group consensus, and proposing a group adaptive adjustment mechanism that can effectively avoid opinion fragmentation. In terms of visualization, a variety of group decision-making visualization tools have been developed abroad, which can realize real-time mapping and consensus visualization of large-scale group opinions, present opinion distribution through clustering algorithms, and intuitively display consensus and divergence.

Domestic research on group consensus decision-making mainly focuses on method optimization and application scenario expansion. Some scholars have proposed consensus methods based on fuzzy mathematics and rough sets for group consensus decision-making problems in fuzzy environments and with uncertain information, solving the problem of imprecise opinion expression[7,8]; other scholars have focused on conflict coordination in group decision-making and designed mechanisms for conflict detection and resolution to improve consensus quality[9]. However, existing research still has deficiencies: first, the distinction of decision-making characteristics among groups of different scales is not clear enough, and there is a lack of targeted consensus decision-making methods; second, research on consensus in large-scale groups is relatively weak, making it difficult to deal with the aggregation and convergence of massive opinions; third, the dynamic analysis of the opinion convergence process is insufficient, failing to effectively reveal the internal mechanism of consensus promotion. Domestic research on group opinion convergence mostly focuses on convergence criteria and speed optimization. Scholars have proposed various consensus degree quantification indicators and constructed optimization models for convergence speed[10-12], but paid insufficient attention to the dynamic depiction and visualization of the convergence process. Existing visualization research mostly uses static charts, such as bar charts to show opinion distribution and line charts to show changes in consensus degree, lacking the presentation of dynamic information such as individual opinion adjustment trajectories and divergence focus evolution, which cannot meet decision-makers' refined cognitive needs for the convergence process[13,14]. In addition, existing visualization schemes fail to fully combine the characteristics of groups of different scales, making it difficult to adapt to decision-making needs in different scenarios, and fail to effectively integrate key information such as sentiment analysis and clustering results, so the practicality of visualization needs to be improved.

3. Analysis and Classification of Consensus Decision-Making Characteristics of Groups of Different Scales

Combined with existing research results and actual decision-making scenarios, this paper divides groups into three categories: small-scale, medium-scale, and large-scale based on factors such as the number of decision-making subjects, the complexity of opinion interaction, and the difficulty of reaching consensus. The specific classification criteria are shown in Table 1.

Table 1. Scale Classification and Characteristic Analysis of Groups

Group Type	Number of Subjects	Interaction Complexity	Consensus Difficulty	Typical Scenarios
Small-scale Group	3-10 people	Low complexity, face-to-face real-time interaction, high connectivity	Low difficulty, few divergence points, easy convergence	Small team project decision-making, small-group academic seminars
Medium-scale Group	11-30 people	Medium complexity, semi-real-time interaction, medium connectivity	Medium difficulty, many divergence points, requiring collaborative coordination	Enterprise department scheme review, medium-sized academic conference seminars
Large-scale Group	More than 30 people	High complexity, mainly indirect interaction, low connectivity	High difficulty, messy opinions, prone to consensus stagnation	Large-scale public policy opinion solicitation, industry standard formulation

4. Construction of Consensus Decision-Making Methods Adaptive to Groups of Different Scales

Based on the decision-making characteristics and consensus difficulties of groups of different scales, this paper constructs differentiated consensus decision-making methods following the principles of scale adaptation and efficiency priority, and designs corresponding consensus decision-making processes and key steps for small-scale, medium-scale, and large-scale groups respectively to achieve dual improvement of consensus efficiency and quality.

4.1 Consensus Achievement Method for Small-Scale Groups

Small-scale groups have a limited number of members, direct information communication, and most viewpoint differences among members stem from personal preferences and insufficient information mastery. The consensus achievement method system for small-scale groups is relatively mature, mainly including the Delphi iterative method, distance consensus measurement method, and fuzzy information consensus algorithm. The Delphi iterative method gradually converges to a unified opinion through multi-round anonymous consultation, feedback, and viewpoint modification. The organizer summarizes opinions and feeds them back to members, who revise their own preferences round by round. This method weakens the influence of expert authority but has many iterative rounds, low efficiency, relies on manual feedback, lacks intelligent guidance, and the process is not visual. The distance measurement consensus method quantifies the degree of divergence between individuals by calculating the Euclidean distance, Manhattan distance, cosine distance, and Hamming distance between individual preferences, sets a consensus threshold, and determines that consensus is reached when the overall divergence is lower than the threshold. This method has no dynamic negotiation guidance mechanism and only judges whether consensus is reached without optimizing the convergence process. The fuzzy consensus algorithm, based on the fuzzy preference theory, measures the consensus level of multiple experts for different alternative schemes and constructs three core consensus evaluation indicators to control the discussion process: the overall group consensus degree integrating expert weights and scheme weights, individual consensus indicators, and scheme consensus indicators. As shown in Figure 1, the algorithm builds a human-machine collaboration system composed of a moderator, an expert group, and a consensus-assisted decision-making system, which can effectively promote the gradual convergence of expert viewpoints in complex decision-making scenarios and efficiently form effective consensus.

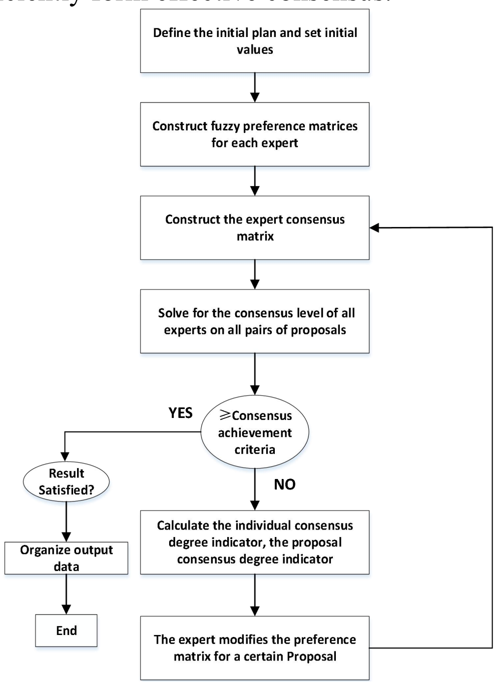

Figure 1. Flowchart of the Fuzzy Consensus Algorithm

4.2 Consensus Achievement Method for Medium -Scale Groups

The number of participants in medium-scale groups is at a medium level, with rich and significantly different internal viewpoints. Relying solely on a single traditional negotiation mode for decision-making discussions will not only greatly increase the cost of information interaction among all parties but also lead to slow viewpoint convergence and low overall decision-making efficiency. Focusing on the decision-making difficulties of medium-scale groups, two different consistency measurement ideas are adopted to construct corresponding decision-making methods. One measures the uniformity of group viewpoints based on the cosine similarity of the included angles of preference vectors, including the group consistency algorithm and the expert consensus discrimination algorithm based on interval number decision-making matrices; the other completes consistency measurement based on closeness, mainly corresponding to group consensus algorithms for processing linguistic evaluation information and fuzzy information. In the solution process of the group consistency algorithm, each expert can independently construct a judgment matrix for each alternative scheme. After the matrix passes its own consistency check, the individual consistency index, the overall group consistency index, and the group consistency index after eliminating a single scheme can be solved in turn. By comparing and analyzing the values of each index, the optimal decision-making scheme can be determined preferentially, and the specific calculation process is shown in Figure 2. For the expert group consensus algorithm based on interval number decision-making matrices, this method first vectorizes the interval number decision-making matrices, calculates the comprehensive consensus index of all experts and the group consensus index after eliminating a single scheme, so as to guide the discussion and exchange among experts and moderately revise individual viewpoints that deviate greatly from the overall consensus. This method has clear theoretical principles, intuitive logic, and simple calculation process. For group decision-making scenarios with natural language evaluation information, a group consensus algorithm based on linguistic evaluation and fuzzy numbers is adopted. This method first performs dimensionless processing on the original data, converts the natural language evaluation values given by experts into trapezoidal fuzzy numbers, then completes the aggregation and integration of multi-source fuzzy information to obtain the comprehensive group evaluation value of each scheme. On this basis, group consensus degree analysis and comprehensive evaluation are carried out, and finally the pros and cons of all alternative schemes are ranked according to the evaluation results. For decision-making discussion scenarios with a small number of experts holding divergent opinions, existing research mainly includes two solutions: the divergent expert identification method based on graphical analysis and the optimization method that takes into account minority opinions to achieve consensus decision-making. Among them, the parallel coordinate method can be used to quantify the convergence degree of group viewpoints, and identify a small number of dissenting experts by comparing expert evaluation data with the critical value of convergence level according to the preset convergence level. As shown in Figure 3, the consensus decision-making method for minority opinions first divides different sub-groups through cluster analysis to accurately locate a small number of divergent experts; then all experts analyze and conduct in-depth discussions around these differentiated viewpoints, and finally achieve the unification of overall opinions.

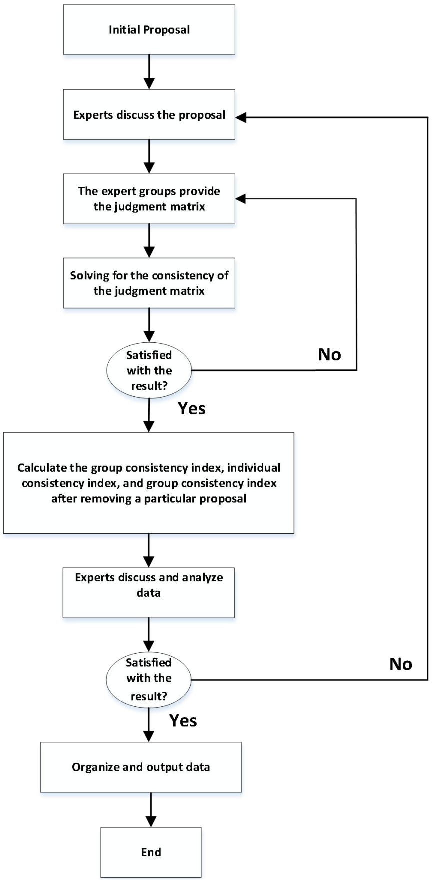

Figure 2. Flowchart of the Group Consistency Algorithm

4.3 Consensus Achievement Method for Large-Scale Groups

In large-scale group decision-making scenarios, due to the large number of participants, scattered viewpoint distribution, and high cost of information exchange among each other, the decision-making mode of full-member synchronous negotiation is not feasible. Therefore, aiming at the decision-making needs of large groups, this paper studies two feasible consensus decision-making technologies: the decision-making method based on entropy weight fusion clustering and the particle swarm optimization consensus algorithm. The entropy weight model decision-making method is for large-group problems with preference information as utility values. It uses entropy weight coefficients to judge the information content of each decision-maker, eliminates individuals with insufficient information contribution, integrates the information of remaining members to construct a scheme utility matrix. It divides member preference clusters through clustering algorithms, determines the weight of each subject combined with the clustering scale, fuses weights to complete the aggregation of the utility matrix and realize the ranking of scheme pros and cons, and constructs relevant evaluation indicators to analyze the rationality of decision-making results. The particle swarm optimization group decision-making algorithm takes the initial expert judgment data as the basis, takes the strong consistency index of the individual judgment matrix as the fitness value, and relies on algorithm iterative optimization to obtain the optimal scheme. This method has high operation efficiency, can effectively shorten the solution time, and alleviate the problems of severe viewpoint conflicts and the inability to terminate group discussions due to non-convergence.

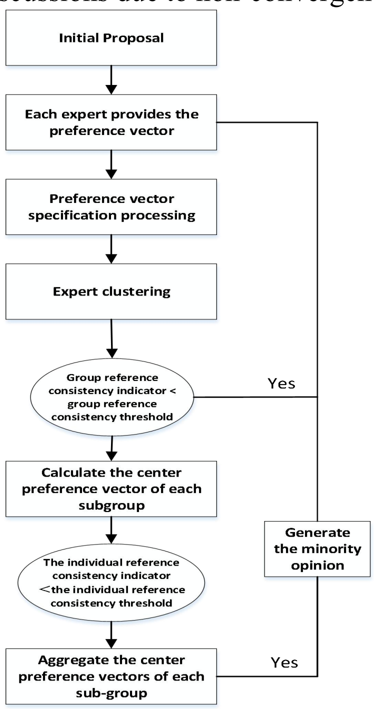

Figure 3. Flowchart of the Consensus Decision-Making Method for Minority Divergent Experts

5. Visualization of the Expert Opinion Consensus Achievement Process and Discussion Results

To solve the problem of the "black box" of the group discussion opinion convergence process, this paper adopts a variety of visualization methods to realize real-time presentation, quantitative analysis, and dynamic traceability of the convergence process, providing intuitive decision-making support for decision-makers. The visualization of expert negotiation and discussion mainly includes the visualization of expert discussion information texts, the visualization of expert opinion consensus achievement, and the visualization of expert discussion results. This paper adopts a tree-view structure to hierarchically visualize discussion text information, and combines relevant consensus achievement algorithms to realize intuitive visualization of consensus evolution and achievement process using clustering technology.

5.1 Visualization of Expert Discussion Information Texts

Constructing a scientific and complete discussion information structure can help participants quickly and accurately mine the potential data content inside the discussion information and effectively improve the overall discussion efficiency. The whole discussion process revolves around expert viewpoints rather than individual experts. Participating experts can not only analyze and evaluate existing schemes and viewpoints but also independently put forward new discussion schemes. All discussion speeches can be presented through a discussion tree structure, but this structure cannot intuitively reflect the final consensus convergence degree of each scheme, and the specific structure is shown in Figure 4. The root node of the constructed discussion tree is used to summarize the overall discussion theme, the secondary nodes under the tree structure correspond to each scheme put forward by experts, and the remaining child nodes correspond to the comments and viewpoints made by experts on the corresponding schemes. Taking discussion theme A as an example, experts have put forward three schemes: Scheme 1, Scheme 2, and Scheme 3, where node 1-1 is the evaluation speech given by other experts on Scheme 1. Group negotiation and discussion activities will generate massive text discussion information, and the discussion tree can intuitively display all relevant text content and realize the visualization of each speech node and its interrelationship. Based on this structure, participants can view the detailed speech text corresponding to any node at any time, making the exchange and discussion among experts more purposeful. At the same time, the discussion tree can clearly characterize the discussion correlation among experts. After determining the overall discussion structure, the semantic correlation degree between different speeches can be distinguished by font size, further enhancing the pertinence of discussion speeches.

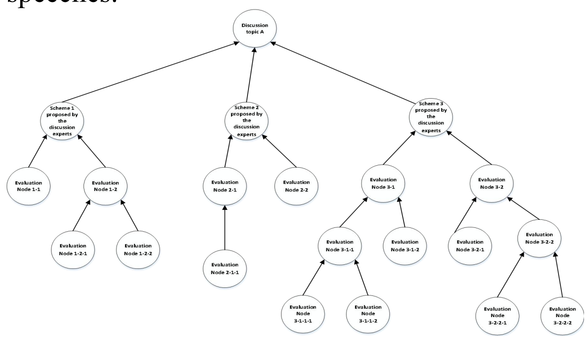

Figure 4. Structure of the Discussion Tree

5.2 Description of the Expert Opinion Consensus Achievement Process

In an interactive discussion scenario, a heuristic clustering algorithm can be used to conduct cluster analysis on expert speech information, and the clustering characteristics of each expert's viewpoints can be presented in visual graphics to identify expert groups with similar viewpoint tendencies. Experts can dynamically adjust their expressions and viewpoints according to real-time clustering results, effectively avoiding group thinking solidification and extreme viewpoint differentiation, and facilitating the smooth formation of the final group decision. The evolution process of expert opinion consensus is shown in Figure 5. First, a preference similarity discrimination threshold is preset. By solving the similarity between normalized preference vectors of each expert, the preference similarity between the first expert and all other experts is calculated in turn. Experts with similarity higher than the set threshold are screened out to form the first opinion sub-group together with the first expert. The above process is cycled and iterated to complete the opinion clustering of all experts, and finally multiple viewpoint sub-groups are divided. Experts in the same sub-group have small viewpoint differences, while there are significant opinion divergences between different sub-groups. The expert clustering results are dynamically displayed throughout the discussion process, and the moderator can rely on such information to guide the discussion, effectively accelerating the convergence process of group viewpoints and improving the formation efficiency of consensus decision-making and the quality of the final scheme.

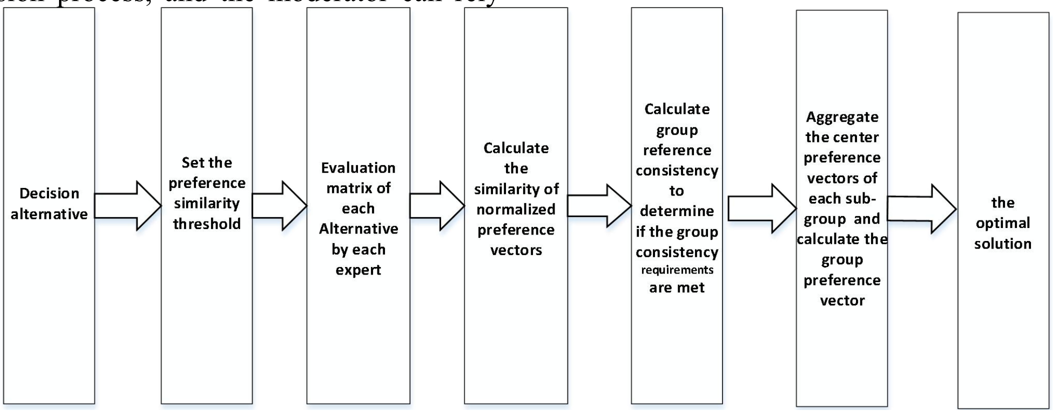

Figure 5. Expert Opinion Consensus Achievement Process

5.3 Visualization of Expert Opinion Distribution and Discussion Results

Opinion distribution visualization is used to present the distribution of decision-makers' preferences at different stages, intuitively reflecting the concentration and divergence of opinions. Different presentation methods are adopted for groups of different scales: Small-scale groups use radar charts for presentation, each decision-maker corresponds to a radar line, and the dimensions of the radar are decision-making evaluation indicators to intuitively compare the preference differences of different decision-makers. Medium-scale groups use grouped bar charts for presentation, each sub-group corresponds to a group of bar charts, the height of the bar chart represents the preference score of the sub-group for each alternative scheme to intuitively compare the opinion differences of different sub-groups; at the same time, pie charts are used to present the opinion proportion of each sub-group, reflecting the overall distribution of group opinions. As shown in Figure 6, after the entire group discussion process is completed, the system comprehensively sorts various consensus schemes finally formed. According to the comprehensive evaluation value corresponding to each scheme, a bar chart is used for intuitive visualization display, clearly presenting the comprehensive pros and cons of different schemes. At the same time, visual statistical analysis is also carried out on the viewpoint distribution of the expert group, and the specific effect is shown in Figure 7. This part mainly focuses on the data statistics and visualization of expert opinion information. By statistically summarizing the viewpoint tendency of each expert for each alternative scheme, a pie chart is used for data display, intuitively presenting the opinion proportion distribution corresponding to each scheme. Large-scale groups adopt a combination of density heat maps and clustering scatter plots for presentation. Density heat maps reflect the distribution density of overall opinions, clustering scatter plots present the opinion aggregation of each sub-group, and different colors represent different sub-groups, intuitively reflecting the preference concentration of homogeneous sub-groups and the opinion divergence of heterogeneous sub-groups. Relying on the above multi-dimensional visualization results, each participating expert can clearly sort out the internal correlation between each speech content, consult the detailed speech text of each node, clarify the evaluation attitude of other experts towards their own viewpoints and various schemes, and fully grasp the overall progress and final conclusion of the entire group negotiation and discussion. This visualization system fully realizes human-machine collaborative interaction, which can effectively promote mutual learning, thinking collision, and viewpoint inspiration among experts, and further improve the comprehensive effect of group discussions.

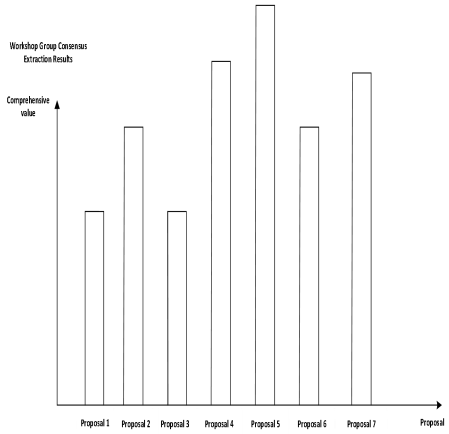

Figure 6. Visualization of Expert Discussion Results

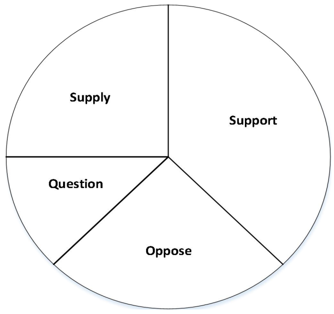

Figure 7 Expert Opinion Distribution Chart

6. Conclusion and Future Prospect

This paper comprehensively discusses the core logic of opinion aggregation and consensus formation in group seminars, and clarifies the effectiveness boundaries of different consensus methods according to expert group scales. On this basis, it introduces the visualization methods of expert seminar information text, expert opinion consensus formation, and expert seminar results. In future research, the following issues need to be further studied: deepen behavior-driven group consensus research. From the perspectives of psychology and sociology, it is necessary to deeply analyze the impact of group members' decision-making behaviors and psychological mechanisms on consensus formation, and to construct a consensus model with stronger practical adaptability; promote the optimization of data-driven and AI-mediated consensus methods. Natural language processing and big data technologies should be used to improve the accuracy of opinion extraction, establish ethical norms for AI intermediary systems, and avoid algorithmic bias; expand interdisciplinary research. Theories from computer science, biology, ethics, and other disciplines should be integrated to explore new mechanisms and methods of group seminar consensus, pay attention to the construction and optimization of social trust networks, and further enrich the research system of group seminar consensus. In general, future research on group seminar opinions and consensus methods should continue to promote the innovation and implementation of consensus methods, give full play to the value of group wisdom, and provide more efficient and operable consensus solutions for various group decision-making scenarios.

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