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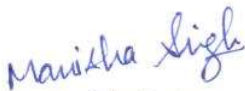
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Acknowledgement

Although the title of this thesis is only in my name, many people have contributed to its preparation. I sincerely thank all those who have helped me complete this thesis work, directly or indirectly. It is my privilege that I have got an opportunity to thank all those people who have helped me.

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Manisha Singh

Abstract

Solving real-world decision-making problems is a complex and uncertain process that involves carefully analyzing possible alternatives by Decision Makers (DMs). It warrants consideration of relative standings in terms of strength, weaknesses, acceptability, cost, consequences, etc., as factors for choosing one of the possible alternatives by the DMs. Thus, to ensure that the best possible solution is obtained, a DM individualistically requires careful analysis and consideration of all available information; it may not be possible to automate the same.

In the case of Group Decision Making (GDM), multiple individuals participate, and each member contributes their knowledge and expertise to achieve a collective decision. Compared with individual decision-making, the GDM ensures the participatory role of each and every DM having diverse perspectives, knowledge and expertise to be made use of. Therefore, the decision-making can be considered to be based on the collaborative approach to achieving consensus. In GDM, each participant may have some unique goal or motivation and their own approach for furnishing their preferences for the alternatives but have the common interest in obtaining the solution, which is agreed by most of them. For this purpose, the DMs provide preferences using a set of evaluations for the set of alternatives. The GDM then requires the aggregation of decision preferences expressed by the individuals, which is to be followed by exploiting the same to work out the possible rank assigned to the decision alternatives. Here, it has to be noted that the above exploitation process does not necessarily check any agreement on a single decision to be prescribed. Hence, it is likely that the solution will not be accepted by some of the participants (i.e., DMs) if they feel that their objectives have not been taken into consideration in solving the problem. Therefore, for the problems requiring cohesiveness

on the agreed solution, an additional phase in the decision process called as the Consensus phase is required. Such a phase incorporates a maximum degree of agreement among the DMs on their preferences before reaching a solution which will be called the consensual solution.

Obtaining a solution that is adhered to by most or all of the DMs is important. For that, Consensus Reaching Process (CRP) is deployed so as to achieve consensus on a decision that is preferred by most or all the DMs. To date, several models of CRP have been proposed, and from the literature of CRP, the assumptions made in the consensus-driven GDM process can be summarized in the following manner: all DMs are consensus-ready, all DMs are continuously available in all the iterations, the CRP may take the differing number of iterations in different scenarios of the GDM process, and lastly, there is a central node/authority that collects the preferences and provides feedback so as to enable the DM to incorporate changes in the preferences for the purpose arriving at a consensus. Taking into account these assumptions, this thesis considers a consensus-driven GDM scenario for working out the observations for the purpose of enrichment of GDM involving a CRP.

Through a detailed literature survey on CRPs in GDM problems, some major issues and challenges are identified in this thesis. After that a possible solution to those problems is proposed. While doing that, to simplify the survey process, we first divide the existing CRPs into four categories and find the research gaps. Lastly, four consensus-based GDM models are proposed, analyzed and characterized to overcome the identified research issues. The first two consensus models developed a focus on tapping the potential of non-expert DMs and facilitating experts in reaching a consensus at once. The third consensus model handles the scenario when some DMs may not be available at

times, and the last proposed model ascertains the trust and security in the decentralized decision-making structure supported by blockchain technology.

The GDM discussed so far considers that the DMs provide preferences based on their knowledge and beliefs, which is aggregated for providing feedback to each individual DM so as to enable them to incorporate changes in their preferences for all possible decision instances. This may be done in multiple rounds until they arrive at a consensus. Here, it should be noted that the thinking process of an individual DM for the purpose of giving the preference in the first round of iteration, considering feedback after every iteration, and incorporating modifications in the preference in the subsequent iterations, is all the human activities of DMs. Therefore, no algorithmic description of the same would be possible. Since the thought process of the mind of a DM has no algorithmic description (just as the 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), working out the preferences regarding possible decision alternatives cannot be carried out by a machine. Moreover, for the purpose of application of GDM at the places such as the group recommender systems, it is obvious that such an approach is an attempt to replace the human mind activity in the algorithmic way wherein the automatic generation of preferences and modification of preferences takes place. Thus, we believe that the consensual opinion obtained with the involvement of human mind, as presented in this thesis, can provide a better decision aid that organizations or individuals use as a reference to achieve consensus in large-scale decision-making situations or emergency situations, or any realistic situations.

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List of Symbols

Chapter 1

$d = \{d_1, d_2, \dots, d_m\}$	Set of decision-makers
$C = \{c_1, c_2, \dots, c_l\}$	Set of criteria
$X = \{x_1, x_2, x_3, \dots, x_n\}$	Finite set of alternatives
$V_p = (v_{ij}^p)_{n \times n}$	Preference provided by decision-maker d_p

Chapter 2

$d = \{d_1, d_2, \dots, d_m\}$	Set of decision-makers
$X = \{x_1, x_2, \dots, x_n\}$	Finite set of alternatives
μ_f	Membership Function
σ_p	Bounded Confidence of Decision Maker d_p
λ	Consensus Threshold
$V^p = (v_{ij}^p)_{n \times n}$	Preference provided by the Decision Maker d_p
$V^a = (v_{ij}^a)_{n \times n}$	Assigned advice to the decision maker
$\bar{V}^p = (\bar{v}_{ij}^p)_{n \times n}$	Modified preference of Decision Maker d_p
$w = \{w_1, w_2, \dots, w_m\}$	Weight Vector
V^c	Collective Preference
cl	Group Consensus Level
$CD(V^p, V^c)$	Degree of Consensus between V^p and V^c
$d(v_{ij}^p, v_{ij}^{GD})$	Distance between v_{ij}^p and v_{ij}^c .
$D(V^p, V^{GD})$	Degree of Deviation between V^p and V^c

Chapter 3

$E = \{e_1, e_2, \dots, e_m\}$	Finite set of experts
$NE = \{ne_1, ne_2, \dots, ne_o\}$	Finite set of non-experts
$P_E^h = (p_{ij}^h)_{n \times n}$	Preference matrix provided by expert $e_h \in E$
$\bar{P}_E^h = (\bar{p}_{ij}^h)_{n \times n}$	Updated preference relation of expert $e_h \in E$
$P_{NE}^l = (p_{ij}^l)_{n \times n}$	Preference matrix provided by non-expert $ne^l \in NE$
$GP^E = (gp_{ij}^E)_{n \times n}$	Group preference relation of experts

$GP = (gp_{ij})_{n \times n}$	Global collective matrix
φ	Mean operator
λ^{inter}	Predefined inter-consensus threshold
λ^{intra}	Predefined intra-consensus threshold
$w_e = (w_e^1, w_e^2, \dots, w_e^m)$	Weight vector of experts
w_e^h	Weight associated with expert e_h
$w_{ne} = (w_{ne}^1, w_{ne}^2, \dots, w_{ne}^o)$	Weight vector of non-experts
w_{ne}^l	Weight associated with non-expert ne^l
$CP^{NE} = (cp_{ij}^{NE})_{n \times n}$	Collective preference of non-experts
$D_{h,NE}^{inter}$	Degree of deviation between P_E^h and CP^{NE}
$CD_{h,NE}^{inter}$	Degree of consensus between e_h and CP^{NE}
$CD_{g,E}^{intra}$	Degree of consensus between e_g and GP^E
$VP^h = (p_{ij}^h)$	Vector representation of preference matrix of e_h
$VCP^{NE} = (cp_{ij}^{NE})$	Vector representation of collective non-experts' preference CP^{NE}
$VGP^E = (gp_{ij}^E)$	Vector representation of collective experts' preference GP^E
H^{inter}	Represents $(k + 1)$ -sphere with centre VCP^{NE} and radius $(1 - \lambda^{inter})$
H^{intra}	Represents $(k + 1)$ -sphere with center VGP^E and radius $(1 - \lambda^{intra})$
$S_1^{h,inter} = (\gamma_{ij}^{h,inter})$	Intersection points lying on hypersphere H^{inter} with centre VCP^{NE} and radius $(1 - \lambda^{inter})$
$S_2^{h,inter} = (\delta_{ij}^{h,inter})$	Intersection points lying on hypersphere H^{inter} with centre VGP^E and radius $(1 - \lambda^{intra})$
$S_1^{g,intra} = (\gamma_{ij}^{g,intra})$	Distance of point VP^h from point $S_1^{h,inter}$
$S_2^{g,intra} = (\delta_{ij}^{g,intra})$	Distance of point VP^h from point $S_2^{h,inter}$
$d_1^{h,inter}$	Distance of point VP^g from point $S_1^{g,intra}$
$d_2^{h,inter}$	Distance of point VP^g from $S_2^{g,intra}$
$d_1^{g,intra}$	
$d_2^{g,intra}$	

Chapter 4

$E = \{e_1, e_2, \dots, e_m\}$	Set of experts
$U = \{u_1, u_2, \dots, u_l\}$	Set of end-users
λ	Consensus threshold
θ	Tolerance value of moderator
$w_e = (w_e^1, w_e^2, \dots, w_e^m)$	Weight vector of experts
$V^p = (v_{ij}^p)_{n \times n}$	Preference vector of expert $e_p \in E$
$T^q = (t_{ij}^q)_{n \times n}$	Preference relation of user $u_q \in U$
$T^C = (t_{ij}^C)_{n \times n}$	Cumulative end-user's opinion
$V^{GD} = (v_{ij}^{GD})_{n \times n}$	Group preference matrix of experts
$AV^p = (av_{ij}^p)_{n \times n}$	Feedback matrix for expert e_p
$D(V^p, V^{GD})$	Degree of deviation between V^p and V^{GD}
$CD(V^p, V^{GD})$	Consensus degree of expert $e_p \in E$
D_{qs}	Distance between the users u_q and u_s
w_q	Weight of the user u_q
$WA(\bar{V}^{GD}, T^C)$	Weighted average of \bar{V}^{GD} and T^C

Chapter 5

$d = \{d_1, d_2, d_3, \dots, d_m\}$	Set of decision-makers
d_p	Denotes decision maker p
$Avail_p^r$	Availability of d_p at round r
α, γ	Control parameter used to control the degree of adjustment in DMs opinion
pf^p	Presence factor of d_p
w_p^{ext}	External weight of d_p
$w_p^{r,int}$	Internal weight of d_p at round r
v_{ij}^p	Preference matrix provided by d_p
v_{ij}^c	Collective preference matrix provided by d_p
cp_{ij}^p	Consensus level on a position (i, j) of a preference of d_p

ca_i^p	Consensus level on an alternative x_i for decision maker d_p
σ_p	Bounded confidence of d_p
D_{ap}	Distance between preference relation V_p and advice generated V_a
D_{pc}	Distance between the collective preference relation V_c and individual preference relation V_p
\bar{v}_{ij}^p	Modified preference matrix of d_p
Sim_{pq}	Similarity between pair of DMs d_p and d_q
N^p	Set of neighbours of DM d_p
d_{β_i}	i^{th} nearest similar decision maker to d_p
Sim_avg_p	Average similarity index for decision maker d_p
S_{N^p}	Cumulative preference of N^p

Chapter 6

$d = \{d_1, d_2, \dots, d_m\}$	Group of two or more decision-makers
$P^k = (p_{ij}^k)_{n \times n}$	Preference provided by decision-maker d_k
$\bar{P}^k = (\bar{p}_{ij}^k)_{n \times n}$	Modified Preference of decision-maker d_k
$D(P^k, P^c)$	Distance between individual decision P^k and collective preference P^c
$ICD(d_k)$	Individual consensus degree of decision-maker d_k
GCD	Group Consensus Degree
$FM^k = (fm_{ij}^k)_{n \times n}$	Feedback matrix to advice decision maker d_k
cl	Consensus threshold
δ	Feedback parameter
$\lambda = (\lambda_1, \lambda_2, \dots, \lambda_m)$	Weight assigned to the decision-makers

List of Abbreviations

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
CRP	Consensus Reaching Process
DCRP	Democratic Consensus Reaching Process
DEA	Data Envelopment Analysis
DM	Decision Maker
DSS	Decision Support System
EA	Ethereum Address
ELECTRE	Elimination and Choice Translating Reality
EuCS	End-users Cumulative Solution
ExCS	Experts' Consensual Solution
GCD	Group Consensus Degree
GCS	Global Consensual Solution
GDM	Group Decision Making
GDSS	Group Decision Support System
IaaS	Infrastructure as a Service
IR-DR	Identification rule- Direction rule
LSGDM	Large Scale Group Decision Making
MAGDM	Multi-Attribute based Group Decision Making
MCDM	Multi-Criteria decision Making
MpMcLSDM	Multi person multi criteria Large Scale Decision Making
OWA	Ordered Weighted Average
PRGDM	Preference Relation based Group Decision Making
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
WA	Weighted Average