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Application of a grounded group decision-making (GGDM) model: a case of micro-organism optimal inoculation method in biological self-healing concrete

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ABSTRACT

The importance of enhancing group decision-making and involving different professionals in decision-making process is a challenging issue in diverse disciplines, engineering, medicine, and also biotechnology. Literature review highlights the basic needs of integrative group decision-making. However, such an integrative group decision-making has not been yet applied in biology and biotechnology areas of research. Using an appropriate decision-making model will aid researchers in accurate experimental decision-making process. In this regard, this study developed an integrative group decision-making model called "Grounded-Group Decision Making (GGDM)" model. The current body of knowledge in group decision-making methods was investigated to understand shortcomings and constrains faced by previous researchers. Accordingly, this study developed the GGDM model which was specifically applied in biological self-healing concrete construction process. As a case of application, the GGDM was applied to validate constructability of diverse inoculation methods in biological self-healing concrete construction, including, vascular network, encapsulation, silica gel, active carbon, and direct use. The GGDM model was implemented within three (3) decision-making sessions. In conclusion, GGDM model provided considerably more accurate, integrative, and consensus-value-based results in validation of inoculation methods. In conclusion, "Adaptation" and "Benchmarking" methods were the most suitable methods in biological self-healing concrete construction process. Moreover, establishment of GGDM model will aid software development in biological decision-making process design in future.

Keywords: Grounded group decision-making method; Decision-making in biotechnology; Biological self-healing concrete

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1. Introduction

Conducting "Group Decision Making" process is a critical issue in diverse disciplines, including, engineering, medicine, sociology, and also, biotechnology. The decision-makings performed in technological innovations can be enhanced by better integration of professionals' inputs to any development process [1]. Wingreen and Levin [2] state the challenges in understanding integration and cooperation of professionals into the decision-making process and how it becomes firmed over evolutionary procedure is at the core of understanding biology. It is critical to understand how professionals may profit from collective decision-making [2]. In this regard, Gupta et al. [3] express that technological advances for scientific detection in decision-making methods and models need to be supported effectively.

2. Literature review

Group decision-making is the root of scientific and technological advances in different disciplines; albeit in biology and biotechnology it has not been grown sufficiently. Literature study was conducted to investigate current body of knowledge in integrated group decision-making. The context of current group decision-making models may be referred to the research initiated by Numi [4] who proposed "Collective Decision Making" approach to improve abilities of group decision-making methods. Numi [4] enhanced predictive accuracy of solution concepts regarding "Collective Decision Making" theory. Kim and Ahn [5] preceded it with the aim of solving the problem of incomplete information of multiple decision-makers, and then proposed "Interactive Group Decision Making". Moreover, Gass and Rapcsak [6] proposed the "Expert Group Aggregation" to appoint voting powers of participates in decision-making process. Kilgour [7] and [8] developed the "Coalition Analysis" method which coordinates decision-makers' actions. Tanino [9], Van Den Honert [10], Chwolka and Raith [11], Xu [12], and Cho et al. [13] state that expert integrative decision-making studies can be improved by considering "preference", and they developed, the "Preference Ordering", "Group Preference Aggregation", and "Preference Relations". Beynon [14] and [15] enhanced the issue by proposing "Aggregation and non-equivalent importance of individual members" and "Inter-Group Alliances". Recently, P´erez et al. [16] and [17] developed a dynamic and heterogeneous method to incorporate both selection and consensus processes. In that base, Ma et al. [18] developed the issue based on subjective preference information and objective decision matrix regarding "Multiple Person" approach in group decision-making. More recently, Bulut et al. [19] enhanced this issue to the "Expert Prioritization" which deals with the lack of consistency control. He used identical decision support rather than weighted expert choices, and lack of measurable criteria. There are some other efforts in the automated decision-making called "group decision making problems" as stated by Lu et al. [20]. In this case, decision-maker's degree of coefficients can be calculated to enhance the final decision [21].

In biology and biotechnology areas of research, there are few decision-making methods developed by researchers for a variety of purposes. For example, Gelfand [22] developed the Russian Foundation for Basic Research (RFBR) as a decision-making system for funding management by agencies. He claims that currently RFBR cannot fulfill adequately agencies' management requirements. Moreover, Lemaire et al. [1] developed the Local Monitoring Committee (LMC) decision-making system for broad numbers of stakeholders. Lemaire et al. [1] state LMC opts for circulation of the minutes of experts meetings, and also issuing progress reports on its collective activities to decision-makers.

3. Problems with current decision-making methods

According to this literature study, the researchers developed different group decision-making methods in order to address various issues. Regarding literature review, some highlighted issues in group decision-making process are; predictive accuracy of solutions, preference ordering, geometric mean aggregation, non-equivalent importance, and voting power of participants, group preferences, coordinate actions of decision-makers, inconsistency in judgments, and ranking solution alternatives. Understanding difficulties and shortcoming of existing group decision-making methods encouraged authors to come up with a new method. The shortcomings of existing group decision-making methods are clustered into two main categories; (A) logistical shortcoming, and (B) technical shortcomings. The following outlines the sub-categories of each category;

(A) Logistical shortcoming:

(A-1) Difficulty in arranging specific time with different participants.

(A-2) Cost of invitation and managing the sessions.

(B) Technical shortcomings:

(B-1) Difficulties associated with "special skill and ability" of participants.

(B-2) Difficulty in attaining a consensus where the number of participants is high.

(B-3) Difficulty in approaching the discussion in the way that participants agree with the right conclusion, not creating a crisis situation.

(B-4) Difficulty to come up with a sound conclusion where different participants have different viewpoints.

4. Grounded group decision making (GGDM) model

In the process of group decision-making, two preliminary contexts are foreseen: (i) in "Structured problem" cases, there is lesser need to conduct group decision-making, and the decision-maker(s) may judge by default. For "non-structured problem" or "creative problem solving" cases the need to conduct a group decision-making is relevant and decision-makers may use specific Group Decision Support System (GDSS) (Klimešová and Brožová [23], (ii) in the decision-making process, there is a "responsible" decision-maker who will come up with the final decision based on observed judgment of decision-makers. This responsible decision-maker in GGDM called "GGDM researcher". Thus, "GGDM researcher" will record the decision process and analyze the decision results.

As mentioned before, "Delphi" can be used in close group discussions (CGD) to conduct "voting", "discussion on devoted", and "next round" procedure. Based on Delphi, the agreement in discussion can be concluded if there is more than 70% agreement on the issue. The GGDM model is suitable if decision-makers in CGDs asked for another CGD round by other "resource relevant to the issue" (other appointed decision-maker(s)). Thus, this study used GGDM as method of data analysis approach. GGDM provides numbers of condition and sub-conditions that should be considered in any case of group decision-making, where there is a need for several CGDs. The GGDM model defines that three conditions may result from each CGD session as follows (Fig. 1);

Condition a: Decision-maker(s) make the decision, if decision-maker(s) know relevant information about a specific part or about the whole issue.

Condition a.1: The decision-maker(s) may select a suitable person to be considered as "resource(s) relevant to the issue" to contribute to a specific part or whole of the issue in another session of CGD.

Condition a.2: The decision-maker(s) may want to know the judgment of the "resource(s) relevant to the issue" before making their decision. Decision-maker(s) may discuss together in a meeting or other modes of communication to make the decision. The decision-maker(s) may choose the decision process of the "resource relevant to the issue" or may make a judgment which is considered as in between of themselves and their decisions.

Condition b: Decision-maker(s) do not make the decision. If decision-maker(s') knowledge is not relevant in a specific part or whole issue.

Condition b.1: Decision-maker(s) may choose or recommend another "resource(s) relevant to the issue" as decision-maker(s) in the similar discipline to judge conclusively instead of another session of CGD.

Condition b.2: Decision-maker(s) may ask for reconsideration on an issue if during the CGD session the understanding about the issue may have improved according to the observation and intuition of the "Decision Researcher" ("Decision researcher" is referred to researcher in this study).

Condition c: Decision researcher will make concluding decision. If in the most recent CGD decision-maker(s), all, made decision without opening any condition including a.1, a.2, b, b.1, and b.2.

Fig. 1 illustrates the GGDM model in the adapted process of decision-making and various conditions. The GGDM provided the mathematical modeling of directions applied to conditions resulted from each CGD as follow;

Direction "a": Decision to be made including response of in the most recent CGD session.

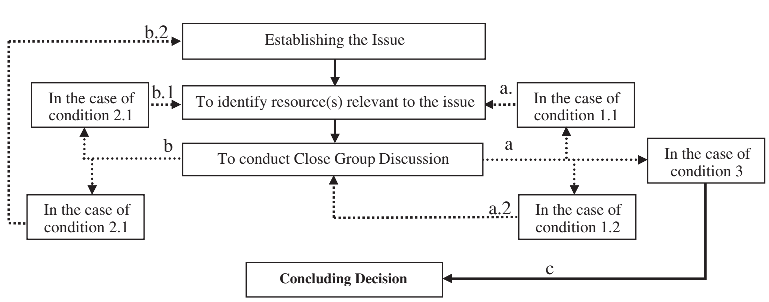

Fig. 1. Grounded group decision making (GGDM) model.

Direction "a.1": Decision to be made based on considering response of decision-maker(s) to the issue, and resource(s) relevant to the issue, which one is less.

Direction "a.2": Decision to be made considering absolute response in the following CGD sessions (another round of Delphi).

Direction "b": Decision to be made considering absolute response of in the following CGD sessions.

Direction "b.1": Decision to be made based on considering absolute response of the resource(s) relevant to the issue introduced by decision-maker(s).

Direction "b.2": Decision to be made considering CGD sessions value (SV) considered by the decision researcher.

Direction "c": Concluding decision to be made based on GGDM concluding formula.

The GGDM formula, named as $FW(a_i)$ is to calculate final weight (FW) of sub-issue number i, (a_i), of discussion.

$$FW(a_i) = \left(\sum_{j=2}^{n} \left(\min\{WP_j, W\underset{j}{\mathrm{Pr}}\} \times SV_j \right) \right) \times a_i, \quad i = 1, 2, 3, \ldots, m \tag{1}$$

where WP_j is assigned weight by participants number j in CGD for sub-issue a_i, $W\,\mathrm{Pr}_j$ is assigned weight by resource(s) relevant to the issue, whom introduced by participants number j in CGD for sub-issue a_i, a_i is a sub-issue of discussion, Max ($FW(a)$) is maximum possible weight can be given for one sub-issue, and SV_j refers to CGD SV considered by the decision researcher which the CGD session included participant number "j".

In the cases where participant(s) did not introduced resource(s) relevant to the issue, min $\{WP_j, W\,\mathrm{Pr}_j\}$ where taken as WP_j. Furthermore, participant(s) in the cases participant(s) did not vote and left the absolute decision for introduced resource(s) relevant to the issue min $\{WP_j, W\,\mathrm{Pr}_j\}$taken as$W\,\mathrm{Pr}_j$. Eq. (2) indicates the consensus calculation in GGDM model for sub-issue a_i based on percentage (%). If the final consensus calculated more than 70%, the alternative is selected and that issue is approved.

$$FW(a_i)/\mathrm{Max}(FW(a)) = \mathrm{Consensus} \quad \text{in } \% \tag{2}$$

5. GGDM model application in biological self-healing concrete development

Biological self-healing cementitious materials are defined as the ability of a cementitious material to repair damage automatically or autonomously by micro-organisms. Currently, the civil engineering researchers in biological self-healing concrete are challenging with finding the appropriate micro-organism sources for their purposes. The researchers attempt to build the biological self-healing concrete which has higher strength, durability, permeability, and remediation qualities in comparison with traditional concrete. In this regard, they are looking for the most appropriate micro-organism sources to build biological self-healing concrete. To date, four methods have been developed to find a suitable micro-organism source, including, isolation, adaptation, DNA (Deoxyribonucleic acid) cloning, and benchmarking [24].

Briefly, the 'isolation" method aids to isolate a targeted micro-organism in pure living cultures and then studied in laboratory experiments. The "adaptation" method is a trait with a current functional role in the life history of a micro-organism that is maintained and evolved by means of natural selection. The "DNA cloning" method allows discrimination of strains that are indistinguishable based on biochemical or serological tests. The "benchmarking" method allows to rationally select the adequate method or combination of methods for the specific kind of investigations or specific information.

This study implemented the GGDM model in finding an appropriate micro-organism sourcing for biological self-healing concrete development. The following section explains method of data collection, survey instrument design, sampling, managing the respondent, and GGDM application for data analysis of the pilot study.

5.1. Data collection

A field expert Delphi structured CGD used as the method of data collection. A structured fixed-format self-reporting decision-making form was prepared to be filled up by decision-makers. Stangor [25] states Likert scaling, and semantic differential both are well-known to capture someone perception, or opinion, on an under testing issue. Thus, the study used five-point Likert and semantic differential rating scale methods. In five-point rating scale, one refers to "Weak" to five refers to "Excellent". The study collected respondent (s) perception based on the instruction in "determining the suitability of methods of microorganism sourcing in biological self-healing concrete development" (Table 1). Totally, seven experts involved in the CGD. Data collection process was conducted in three group decision-making sessions. In each decision-making process, firstly, the researcher recorded the general information about the respondent(s). Next, the

Table 1
GGDM analysis process on validation of selection of thermal and lighting conditions in building indoor environment

		Validation session 1							Validation session 2										Validation session 3							
		Participant 1			Participant 2				Participant 3			Participant 4			Participant 5				Participant 6			Participant 7				
Validation aspect		WP	WPr = c-	c-WP	WP	r-WP = c-	c-WP	SV	WP	WPr =	c-WP	WP	WPr = WP6	c-WP	WP	WPr =	c-WP	SV	WP	WPr = -	c-WP	WP	WPr = -	c-WP	SV	GGDM consensus
Methods of micro-organism sourcing	Isolation	3	2	2	1	2	1	1	2	1	2	1	1	1	–	1	1	3	1	–	1	–	1	1	4	n-Aprv.
	Adaptation	3	5	3	4	5	4	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	Aprv.
	DNA cloning	3	1	1	1	1	1	1	1	1	1	1	2	1	–	1	1	3	2	–	2	–	2	2	4	n-Aprv.
	Benchmarking	2	4	2	3	4	3	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	Aprv.

Note: WP: Participant's weight assigned to the validation aspect, c-WP: conclusion of Participant's weight assigned to the validation aspect considered asmin {WP_j, W Pr_j}, WPr: weight assigned to the validation aspect by Participant introduced resource relevant to the issue, -: Participant did not assigned weight to the validation aspect, SV: CGD Session Value considered by the GGDM researcher, Aprv.: the validation aspect is approved based on GGDM Consensus rate of more than 70% agreement, n-Aprv.: the validation aspect is not approved based on GGDM Consensus rate of not more than 70% agreement.

researcher briefed the aim of discussion and defined the terminologies used in. The researcher filled up the form based on expert's explanations and justifications, and then confirmed the written responses with them. In final stage, GGDM researcher asked for cross-vote-weighting of decision-makers to each other. After the three group decision-making sessions, GGDM researcher weighted each SV subject to reliability of final issue of decision-making to the discussed issue is decision-making session (Table 1).

5.2. Data analysis

To analyze the collected data, the research used the Grounded Group Decision Making (GGDM) method. According to GGDM results, suitability validation on methods of micro-organism sourcing, "Isolation" and "Benchmarking" methods of micro-organism sourcing suitable for biological self-healing concrete development have been determined by 70% saturation regarding experts' justifications and consensus (Table 1). The results align with constructability issues related to biological self-healing concrete.

The research found the results and analysis of GGDM with much more less logistical and technical difficulties. In comparison with traditional group decision-making methods, the results of the GGDM model are much more reliable and integrative. To sum up, the mathematical modeling of GGDM model was found to be more trustable and applicable. In implementing GGDM method, the mathematical model may vary case by case. This issue is needed to be developed further in future studies.

6. Conclusion

The GGDM model provides considerably more accurate, integrative, and consensus-value-based results by a systematic group decision-making process. In the systematic decision-making process, GGDM model validates the methods of micro-organism sourcing based on weight assigned by participants within three sessions of Delphi. This approach has specific advantages as compared to the difficulties faced in traditional group decision-making methods. The GGDM approved the Adaptation and Benchmarking items based on consensus rate of more than 70%. The GGDM model has a great potential to be enhanced as software in biological decision-making process design.

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References

[1] O. Lemaire, A. Moneyron, J.E. Masson, Interactive technology assessment and beyond: The field trial of genetically modified grapevines at INRAColmar The Local Monitoring Committee, PLoS Biol. 8(11) (2010) 2–7.

[2] N.S. Wingreen, S.A. Levin, Cooperation among microorganisms, PLoS Biol. 4(9) (2006) 1486–1488.

[3] R. Gupta, M.H. Michalski, F.R. Rijsberman, Can an infectious disease genomics project predict and prevent the next pandemic? PLoS Biol. 7(1) (2009) 2–4.

[4] H. Numi, Approaches to collective decision making with fuzzy preferences relations, Fuzzy Sets Sys. 6 (1980) 249–259.

[5] S.H. Kim, B.S. Ahn, Interactive group decision making procedure under incomplete information, Eur. J. Oper. Res. 116 (1990) 498–507.

[6] S.I. Gass, T. Rapcsak, A note on synthesizing group decisions, Decis. Support Syst. 22 (1998) 9–63.

[7] M. Kilgour, Coalition analysis in group decision support, Group Decis Negot. 10 (2001) 159–175.

[8] M. Kilgour, Y. Chen, K.W. Hipel, Multiple criteria approaches to group decision and negotiation. in: M. Ehrgott, J. Figueira, S. Greco (Eds.), Trends in Multiple Criteria Decision Analysis, International Series in Operations Research and Management Science. vol. 142, Springer, New York, NY, 2010, pp. 317–338.

[9] T. Tanino, Fuzzy preference ordering in group decision making, Fuzzy Sets Sys. 12 (1984) 117–131.

[10] R.C. Van Den Honert, F.A. Lootsm, Group preference aggregation in the multiplicative AHP, the model of the group decision process and Pareto optimality, Eur. J. Oper. Res. 96 (1996) 363–370.

[11] A. Chwolka, M.G. Raith, Group preference aggregation with the AHP-implications for multiple-issue agendas. J. Oper. Res. 132 (2001) 176–186.

[12] Z. Xu, A survey of preference relations, Int. J. Gen. Syst. 36 (2007) 179–203.

[13] Y. Cho, K. Cho, A loss function approach to group preference aggregation in the AHP, Comp. Oper. Res. 35 (2008) 884–892.

[14] M.J. Beynon, A method of aggregation in DS/AHP for group decision-making with the non-equivalent importance of individuals in the group, Comp. Oper. Res. 32 (2005) 1881–1896.

[15] M.J. Beynon, The role of the DS/AHP in identifying inter-group alliances and majority rule within group decision making, Group Decis Negot. 15 (2006) 21–42.

[16] I.J. P´erez, S. Alonso, F.J. Cabrerizo, Jie Lu, E. Herrera-Viedma, Modelling heterogeneity among experts in multi-criteria group decision making problems, in: Proceedings of the 8th international conference on Modeling decisions for artificial intelligence (MDAI'11), Springer-Verlag, Berlin, 2011, pp. 55–66.

[17] I.J. P´erez, S. Alonso, F.J. Cabrerizo, Jie Lu, E. Herrera-Viedma, A mobile decision support system for dynamic group decision making problems systems, man and cybernetics, Part A Syst. Humans, IEEE 40 (2010) 1244–1256.

[18] J. Ma, Q. Zhang, D. Zhou, Z. Ping Fan, A Multiple Person Multiple Attribute Decision Making Method Based on Preference Information and Decision Matrix, Department of Information Systems, City University of Hong Kong, Kowloon Tong, Hong Kong, China Malcolm, 2011.

[19] E. Bulut, D. Okan, K. Tuba, Y. Shigeru, Use of consistency index, expert prioritization and direct numerical inputs for generic fuzzy-AHP modeling: A process model for shipping asset management, Expert Syst. Appl. 39 (2012) 1911–1923.

[20] B. Lu, G. Yang, W. Zhang, D. Zhang, A new approach to group decision-making for cooperative monitoring and diagnosis of manufacturing equipment, Adv. Sci. Lett. 4(4–5) (2011) 1833–1837.

[21] G. Zakria, Z. Guan, X. Shao, Y. Riaz, U. Hameed, Selection of simulation software for manufacturing system: Application of analytical hierarchy approach in multi criteria decision making, Adv. Sci. Lett. 4(6–7) (2011) 2152–2158.

[22] M. Gelfand, Doing science in uncertain times, PLoS Biol. 2(7) (2004) 886–892.

[23] D. Klimešová, H. Brožová, GIS as knowledge maps in group decision making, Int. J. Math. Models Methods Appl. Sci. 6(1) (2012) 20–29.

[24] L. Fulton, Biomass and Agriculture Sustainability, Markets and Policies, International Energy Agency (IEA) biofuels study–interim report: Result and key messages so far, (2004) 105–112.

[25] Ch. Stangor, Research Methods for the Behavioral Sciences. 3rd ed., University of Maryland, Houghton Mifflin Company, 2007, p. 75.